Analysis of flow behavior as influenced by reservoir with flow regularization

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Abstract

Understanding the behavior of reservoirs with flow regularization formed by hydroelectric power plants is essential for assessing water availability and, consequently, for planning the use of water resources, especially in downstream positions. The operationalization of reservoirs can be influenced both by climatic characteristics and by the consequences resulting from human actions in the basin. Therefore, the objective of this study was to evaluate the existing relationships between the inflows and outflows of a reservoir, as well as with the conventional streamflow gauge stations downstream of the dam. In addition, the aim was also to evaluate trends in the behavior of minimum, average and maximum flows, in the post-operation period, considering the characteristics of rainfall and irrigation in the region. The results indicated that reservoir operationalization is strongly related to the behavior of inflows, especially when considering analyses in quarterly periods, also affecting the flow in the streamflow gauge stations downstream. Moreover, a reduction was also verified in all variables analyzed related to inflows and outflows, as well as in the stations downstream of the dam, except for the maximum flow in the station farthest from the reservoir, which showed a stationary behavior. The reductions observed in the flows may be related to the increase of almost three times in the area irrigated by center pivot in the basin; however, the same cannot be said in relation to the annual rainfall regime of the region, since it showed a stationary behavior for most stations evaluated.

1. Introduction

In Brazil, hydroelectricity is still the main source of power generation in the country. Hydroelectric plants are composed of large water reservoirs that are normally used to form reserves in periods of higher water availability, which can be used to attenuate scarcity during the dry season (Setti et al. 2000). Thus, the construction of reservoirs causes changes in natural hydrological regimes, storing water and releasing it according to the temporal pattern required by demand.

In global terms, the understanding of the dynamics of water storage in lakes and reservoirs needs to be improved (Busker et al. 2019). According to Nourani et al. (2020), the hydrological and meteorological parameters that affect the amount of water stored in a reservoir may include rainfall, the volume of water released to meet downstream needs and also, with special emphasis, the inflows.

According to Schaefli (2015), these structures are vulnerable to climate change, but other factors such as changes in land use and occupation and demand for irrigation upstream of the reservoir (Splading-Fecher et al. 2014) can directly influence water availability for electricity generation. The analysis of the behavior of these variables over the years has become increasingly relevant, due to the possibility of identifying trends that help in the management of water within a territory or watershed.

Pereira et al. (2018), analyzing the variability of rainfall throughout the territory of Minas Gerais state, from 1891 to 2017, identified a trend of reduction in the rainy season for the northern region, no change in behavior for the central region and a trend of increase in the rainy season for the south and extreme west of the state, hence highlighting the existence of changes in the behavior of rainfall distribution in the state.

Other studies such as that of Abeysingha et al. (2016), besides analyzing the rainfall trend also evaluated the behavior of factors related to human activities, aiming to understand the decreasing trends observed in the flows of the Gomti River in India, identifying that the growths of irrigation and population were the major responsible for the extraction of water in the basin. In this context, Silva et al. (2020) evaluated the behavior of the flow, rainfall and land use data in the Paracatu River Basin, located in the state of Minas Gerais, Brazil, and also found trends of reduction in the flows in all streamflow gauge stations considered, and despite not finding changes in rainfall behavior, they highlighted that activities associated with irrigated agriculture may be negatively affecting the sustainability of water resources.

In Brazil, the National Agency for Water and Basic Sanitation (*Agência Nacional de Águas e Saneamento Básico* - ANA) highlighted in its Irrigation Atlas that this activity showed more significant increases in São Paulo, Minas Gerais, Tocantins, Bahia, Rio Grande do Sul and, more recently, in Goiás. The study also identifies that in 2019 there were 1,556 Mha irrigated by center pivots (the fastest growing system today), and this area is 50 times larger than the area mapped in 1985. It also pointed out that the largest centers are located in Minas Gerais (28.8%) and Goiás (17.3%), although all Brazilian states showed growth in the medium and short term (ANA, 2021).

Thus, the expansion of irrigated areas has led to a considerable increase in the use of surface water and also in the extraction of groundwater, leading to risks in relation to the maintenance of water availability in watercourses. This type of situation can contribute to depleting the amount of water stored in the reservoirs, and these analyses should always be performed in an association with the behavior of factors related to climate, such as rainfall. It is worth mentioning that, in addition to irrigation, the existence of small dams upstream of the reservoirs can also influence the amount of inflows available for reservation.

A study conducted by Shadkam et al. (2016) showed that, although the reductions in the inflows in Urmia lake followed the reductions observed in rainfall, the variability of the inflows was more pronounced than the variability in rainfall, suggesting that the use of water for irrigation increased the pressure on the availability of water in the basin and caused a decrease in flows.

Thus, studying the relationships between the inflows and outflows of a reservoir can be fundamental to determine and/or plan efficient operational regimes, as in the work of Chang and Chang (2001), who determined ideal operations schedules for a reservoir by using time series of inflows.

In this context, the present study was conducted aiming to: 1) evaluate the relationships between the inflows and outflows of the Queimado HPP reservoir; 2) to evaluate the relationships between the outflows and the flows of conventional streamflow gauge stations located downstream of the Queimado HPP reservoir, highlighting minimum, average and maximum annual flows; and 3) to evaluate the behavior trends of minimum, average and maximum flows and their relationship with the annual rainfall regime and the advance of center pivot irrigation in the study region in the post-operation period of the Queimado HPP reservoir.

2. Material And Methods

2.1. Study area

For the study, the reservoir of the Queimado Hydroelectric Power Plant (Queimado HPP) was selected, located in the Preto River Basin (10,325 km²), sub-basin of the Paracatu River, within the São Francisco River Basin. The Preto River Basin covers part of the Federal District (13%) and the states of Goiás (22%) and Minas Gerais (65%).

The Queimado HPP (Fig. 1), owned by the consortium between the Minas Gerais Energy Company (*Companhia Energética de Minas Gerais* - CEMIG) and the Brasília Energy Company (*Companhia Energética de Brasília* - CEB), is located in Palmital de Minas, a district belonging to the municipality of Cabeceira Grande, Minas Gerais.

Its construction started in 2000 and ended in 2004, when it went into full commercial operation. With installed power of 105 MW, the Queimado HPP generates enough electricity to serve 300,000 consumers. The maximum height of the dam is 70 meters, with about 36.26 km^2 of flooded area. The maximum and minimum water levels in the reservoir are 830 and 811 meters, respectively.

The reservoir formed by the Queimado HPP has a useful volume of 389.46 hm^3, with a maximum volume of 477.97 hm^3 and a minimum volume of 88.51 hm^3, according to data from the daily bulletin provided on 17/05/2021 by ANA.

The conditions for its operation must consider multiple uses, as established by ANA, through Resolution No. 147 of March 2, 2015, with a minimum discharge of 8.8 m^3.s^{-1} in the rainy season (November to April) and 17 m^3.s^{-1} in the dry season (May to October). According to the National Electric System Operator (*Operador Nacional do Sistema Elétrico* - ONS), the reservoir has an outflow restriction that, when combined with the incremental flow in the Queimado/Unaí segment, cannot exceed the flow of 300 m^3.s^{-1} in the municipality of Unaí, thus assisting in flood control (ONS 2020).

2.2. Hydrological data

From the inventory provided by ANA, 76 streamflow gauge stations were identified in the Preto River Basin. The selection of the stations to be used in the present study was made according to the following criteria: i) to be located in the Preto River Basin; (ii) to be downstream of the Queimado HPP reservoir; and iii) have at least 10 years of data, considering the base period from 2005 to 2019, after the construction and stabilization of the operational activities of the Queimado HPP.

Using the above criteria, it was found that, of the 76 stations existing in the Preto River Basin, only 22 are downstream of the Queimado HPP reservoir. However, when checking the availability of observed data for these stations, only 3 of them met criterion iii, and these were selected for the study: Fazenda Limeira (42460000), Unaí (42490000) and Porto dos Poções (42600000), referred to in Fig. 2 as Q1, Q2 and Q3, respectively. The historical series of these stations were obtained on the Hidroweb platform (https://www.snirh.gov.br/hidroweb/serieshistoricas), which includes data from the National Hydrometeorological Network (*Rede Hidrometeorológica Nacional* - RHN), under the responsibility of ANA.

The historical records of inflows (Qin) and outflows (Qout), associated with the operationalization of the Queimado HPP reservoir, were also obtained from ANA, through the platform of the Reservoir Monitoring System (*Sistema de Acompanhamento de Reservatórios* – SAR) (https://www.ana.gov.br/sar/), which provides, among other data, the daily inflows from 1993 to 2019 and outflows from 2003 to 2019.

According to information collected from CEMIG, the outflows are calculated from information on the performance of the turbine-generator set, a function of gross or net water head by power and the spillway discharge curve, obtained by small-scale models or mathematical modeling. For the outflows, there is a control point for reference, considered by ANA and called UHE Queimado Barramento Telemetry Station (code 42459080), from which the average daily flow is obtained from the daily outflow data (http://www.snirh.gov.br/hidrotelemetria/Mapa.aspx).

On the other hand, the inflows are obtained by the water balance equation, considering the variation of the stored volume over time and the volume that left the reservoir in that same time interval. Thus, the estimates of inflows are not obtained from a specific station or control point and, therefore, the location of Qin measurements does not exist in Fig. 2.

The main information for the telemetry streamflow gauge station that collects Qout data and for the other three conventional streamflow gauge stations (Q1, Q2 and Q3) used in the study is presented in Table 1.

Table 1
Characteristics of conventional streamflow gauge stations and the telemetry streamflow gauge station located in the Queimado HPP

Code	Name	Stations	Latitude	Longitude	Area (km^2)	Type
42460000	Fazenda Limeira	Q1	-16.2089	-47.2325	3890	Conventional
42490000	Unaí	Q2	-16.3494	-46.8800	5360	Conventional
42600000	Porto dos Poções	Q3	-16.8397	-46.3572	9400	Conventional
42459080	UHE Queimado Barramento	Qout	-16.2106	-47.3233	3657	Telemetry

To check the rainfall behavior in the region, during the period of operation of the reservoir, 19 rain gauge stations (Fig. 2) located within the Preto River Basin and its surroundings (buffer of 50 km), with minimum availability of 10 years of data within the base period from 2005 to 2019, were selected to evaluate the existence of possible trends of the rainfall regime of the region of interest.

Historical rainfall data were also obtained from the Hidroweb platform of ANA, and only those stations that met the same criteria established in iii for the streamflow gauge stations were selected. Therefore, the data used were related to 19 rain gauge stations in total, 8 of them located within the Preto River Basin (Fig. 2).

After systematization of the data, the annual values of average flow (Q_{avg}), average minimum 7-day flow (Q_7) and maximum daily flow (Q_{max}) were obtained for each of the historical series of flow (Qin, Qout, Q1, Q2 and Q3), based on the hydrological years from 2005/2006 to 2018/2019. Based on the analysis of rainfall and streamflow data from the stations located in the Preto River Basin, it was identified that the hydrological year for the study region begins in November and ends in October.

Monthly Q_{avg} values were also estimated to be evaluated under two conditions: on yearly scale, considering the average flow values obtained for each month, of each year, within the period considered, and quarterly scale, considering the average flow obtained for each month within the selected quarter. The establishment of the months for each quarter was based on the definition of the hydrological year of the region: the first (1st) quarter comprised the months of November, December and January; the second (2nd) comprised the months of February, March and April; the third (3rd) comprised the months of May, June and July; and the fourth (4th) comprised the months of August, September and October, following the definition of the hydrological year of the region, thus seeking to evaluate the representativeness of the data according to the seasonality of the region.

It is emphasized that the daily flow data from the conventional stations of ANA (Q1, Q2 and Q3), used to estimate Q_{avg}, Q_7 and Q_{max}, were subjected to a process of data processing/consistency and subsequent filling of gaps by applying modeling with the use of machine learning algorithms. The Qin and Qout flow series showed no gaps within the period under analysis.

For the historical rainfall series, the values of total annual rainfall were obtained for each rainfall station selected in the study for the same base period of the flows.

Given the conditions for which this study was carried out, we sought to check the hydrological variability in the flow series resulting from the influence of the operation of the reservoir formed by the Queimado HPP, whose operation began in 2004. As a result, a base period from 2005/2006 to 2018/2019 was adopted for the analyses, contemplating a historical series with 14 years of records, in order to avoid the joint evaluation of periods before and after the construction of the flow regularization reservoir.

Although the World Meteorological Organization (*Organização Meteorológica Mundial* - OMM) indicates that the climate of a region should be characterized on the basis of a minimum period of 30 years (OMM 1975), the use of long series may not be representative when there is influence of anthropic effects on the data, resulting, for example, from the construction of reservoirs (Tucci 2003), thus demonstrating that the base period adopted in this study, for statistical trend analyses, is consistent with the situation presented.

2.3. Exploratory analysis of the relationship between flows

Exploratory analysis of flow behavior as influenced by the Queimado HPP reservoir was performed using Pearson's correlation analysis (Wu et al. 2018). For this, two time scales (yearly and quarterly) were considered to evaluate the degree of association between the series of average inflows, outflows, Q1, Q2 and Q3, within the base period considered.

Pearson's correlation (r) is the most used correlation measure and is sometimes called the linear correlation coefficient because it measures the linear association between two variables. If the data are on a straight line with a positive slope, then r = 1, if the line has a negative slope, then r = -1 (Helsel et al. 2020).

Thus, the correlation between the annual outflows (dependent variable) and the annual inflows (independent variable) and, subsequently, the correlation between the outflows, now considered as an independent variable, and the average flows (yearly and quarterly scales) of conventional streamflow gauge stations located downstream of the dam (Q1, Q2 and Q3), taken as dependent variables, were evaluated.

The classification of the correlation between the variables was defined based on the proposition presented by Bozzoni et al. (2020), according to which the correlation is moderate for r values above 0.5, strong for values above 0.7 and very strong for values above 0.9.

2.4. Trend analysis

2.4.1. Mann-Kendall and Modified Mann-Kendall Method

As recommended by OMM (1988), the nonparametric test proposed by Mann (1945) and Kendall (1975) was adopted for the analysis of the time series of flow and rainfall used in the present study. This test was used because it does not require normal distribution of data (Yue et al. 2002), because it is a robust method (Helsel and Hitch 2002) and because it copes well with gaps in the series with data below the detection limit.

The Mann-Kendall test consists in comparing each value of the series with the other ones, in a sequential order, counting the number of times the other values are greater than the observed data (Back 2001).

The test assesses the following hypotheses: H_0 - the data are independent and equally distributed (there is no trend) and H_1 - the data have a monotonic trend over time (there is a trend). In a two-sided trend test, H_0 must be accepted for a given level of significance α, if for the quantile $Z_{\alpha/2}$ of a standard normal distribution $|Z| \leq Z_{\alpha/2}$.

Establishing the significance level divides the domain of the test variable into two regions. One of these regions consists of values of the test variable that lead to the acceptance of H_0. This region is called the acceptance region. The other region consists of the set of values of the test variable that lead to rejection of H_0, called a critical region. The significance level adopted in this study was 5%, being associated with a value of $Z_{\alpha/2} = Z_{0.025} = 1.96$.

For applying the Mann-Kendall test, the data need to be random and independent (Neeti and Eastman 2011) and, because of that, these conditions were previously analyzed by applying the run test and serial autocorrelation test, respectively (Salviano et al. 2015). The latter compares the values of the series in a given period and the values of the same series in lagged time periods. For these lags, the results are evaluated by correlograms. In this study, a significant autocorrelation was considered, evaluating the data found for *lag*-1, as recommended by Abeysingha et al. (2016).

When the series showed characteristics of randomness and independence from each other, the Mann-Kendall test was applied. However, for those series that showed non-random and dependent behavior, the modified Mann-Kendall test was applied, since it is necessary to adjust the method for the correlation to be taken into account (Hamed and Rao 1998).

The analyses to check for randomness and independence between the series, as well as the application of Mann-Kendall trend tests or, when necessary, modified Mann-Kendall test, were performed using R software.

2.4.2. Sen's Slope Method

As the Mann-Kendall test does not provide the magnitude of the trends, when detected, the Sen's Slope method was used. This method was proposed by Sen (1968) and improved by Hirsch et al. (1982), and can provide a realistic measure of trends, when verified, in a historical series (Ferrari 2012).

Sen's Slope is widely used in studies on the temporal behavior of hydrometeorological series (Silva et al. 2015; Dubey et al. 2020) and is estimated by applying the statistic Q_{ij}, which can be calculated according to Eq. 1.

$$Q_{ij} = \frac{x_j - x_i}{j - i}, \ with i < j \qquad \text{Equation 1}$$

Where, x_j, x_i are the values of the variables under study in years j and i, respectively. If there are n values in the analyzed series, then the number of estimated pairs of Q is given by $N < n(n-1)/2$. The n values of Q_{ij} are classified from lowest to highest, and the median of the Sen's Slope estimate is calculated as shown in Eq. 2.

$$Q_m = \begin{cases} Q_{[(n+1)/2]}, ifnisodd \\ \frac{Q_{[n/2]} + Q_{[(n+2)/2]}}{2}, ifniseven \end{cases} \quad \text{Equation 2}$$

The signal of Q_m reflects the trend (increase or decrease) of the data, while its value indicates the magnitude of the trend. To determine whether the median slope is statistically different from zero, the confidence interval of Q_m at the specific probability is obtained.

The Sen's Slope confidence interval can be calculated by applying Eq. 3.

$$C_\alpha = Z_{1-\alpha/2}\sqrt{V(S)} \quad \text{Eq. 3}$$

Where, $V(S)$ is calculated according to the preliminary assessment of the data in relation to the applicability of the Modified Mann-Kendall or Mann-Kendall methods; $Z_{1-\alpha/2}$ is obtained from the standard normal distribution table and was considered in the present study for the significance level of 5% (α = 0.05).

So, $M_1 = (n - C_\alpha)/2$ and $M_2 = (n + C_\alpha)/2$ are calculated, representing the lower and upper limits of the confidence interval.

3. Results And Discussion

3.1. Exploratory analysis of inflow and outflows

Figure 3 shows the variation of the daily inflow (Fig. 3A) and outflows (Fig. 3B), considering each of the years of study adopted here (2005 to 2019), which are represented by the blue dots. Thus, for the same day of a given month, 14 flow values are represented.

On the other hand, the red dots represent the daily average values obtained between the years, that is, for a given day of the month, a single flow value is represented, calculated from the average of the 14 years analyzed.

It is possible to note in Fig. 3A that the inflows have an evident seasonal behavior, with higher flows between the months of November and April, representative of the rainy season of the region, and lower flows between May and October, months characterized by the reduced incidence of rainfall.

It is also clear that the inflows, especially for the rainy season, show high amplitude, as in February, when the daily flows ranged from 13.6 to 280 $m^3.s^{-1}$ throughout the historical series considered. For the dry season, the variability amplitude is smaller, for instance in July, when the flows varied between 3.5 and 51 $m^3.s^{-1}$.

Figure 3B, which represents the behavior of outflows, shows that in a few moments, from the rainy season, especially in December, the magnitude of the flows exceeded the value of the inflows, which is not normally expected. These values, however, were recorded between 2005 and 2006, a period marked by the beginning of the reservoir's activities, which may mean that adjustments were still being made for its correct operation.

In general, for the outflows, the flow behavior shows a higher constancy throughout the year, evidencing the regularization of flows promoted by the reservoir. Nevertheless, there are still differences in outflows for different years, considering the same day, although in much smaller proportions than the inflows.

Figure 4 represents the mass diagram, as proposed by Rippl (1883), constructed from the historical series of inflows and outflows of the reservoir, where it is possible to observe less abrupt changes in the slope of the diagram for the outflows, compared to the observed changes for the inflows.

The analysis of flow behavior shows that the inflow has greater variability due to the seasonality of the rainfall regime, which is why there is a more marked growth of the accumulated flows in some periods of the year (November to April). On the other hand, the outflow shows a more regularized behavior overall years within the period, influenced precisely by the operation of the Queimado HPP reservoir, which balances the flows along the hydrography, minimizing drought and flood events throughout the dry and rainy seasons, respectively.

The results found in the analysis of correlation between the inflows and outflows are presented in Fig. 5, both for the yearly scale and for the quarterly scale.

The correlation between the outflows and inflows considering all months of the year, over the period considered, was equal to 0.74, classified by Bozzoni (2020) as a strong correlation. Therefore, it is a satisfactory result, demonstrating that the values of the inflows are determinant for the operationalization of the reservoir.

When analyzing the data on a quarterly scale, even higher correlations are obtained, especially for the first (0.82), second (0.86) and third (0.88) quarters, highlighting the greater dependence of the outflows regarding the seasonal pattern's characteristic of the inflows, hence interfering in the Queimado HPP reservoir's operating conditions.

For the fourth quarter, the correlation value found was 0.73, close to the value estimated for the yearly correlation. The reduction of this correlation probably occurs due to the greater reservoir regularization activity in this period, which should meet the downstream demands even if the inflows show significant reductions.

Analyses of this nature are corroborated in studies such as that of Passaia and Paiva (2019), who evaluated which variables (inflows, water level, volume and day of the year) govern the behavior of the outflow of 150 reservoirs located in Brazil and controlled by the ONS. According to the authors, the variable that best explained the behavior of the outflow was the inflow, and an average correlation value of 0.79 was found, which demonstrates the explanatory importance that the inflow represents in determining the process of operationalization of reservoirs.

Thus, the results of this study show that understanding the behavior of inflows becomes essential for the management and operational planning applied to the Queimado HPP reservoir. The existence of climatic and/or anthropic variability may cause interference in the availability and storage of water in the reservoir, impacting both the generation of electricity and the other activities implemented in the basin, downstream of the reservoir, which are users of water.

This concern is more evident in Fig. 4, which shows a change of slope for the two lines representative of the behavior of outflows and inflows, at the end of the studied period, especially from the year 2016, which means that the accumulated flows over the years, in these positions of hydrography, is reducing and resulting in lower water availability in the basin.

Table 2 presents the results of the correlation analysis between the average outflows and the average flows obtained from conventional streamflow gauge stations Q1, Q2 and Q3.

Table 2
Correlations obtained between the outflows of the Queimado HPP reservoir and the conventional streamflow gauge stations Q1, Q2 and Q3 on yearly and quarterly scales, throughout the study period

Period	**Correlation Coefficient (r)**		
	Qout and Q1	**Qout and Q2**	**Qout and Q3**
Yearly	0.97	0.90	0.62
1st Quarter	0.92	0.90	0.67
2nd Quarter	0.99	0.96	0.74
3rd Quarter	0.98	0.91	0.88
4th Quarter	0.99	0.98	0.84

The results show that the correlations between the outflows and the flows in station Q1, for all periods analyzed, were characterized as very strong, indicating a high degree of association between the flow data of the conventional streamflow gauge station downstream and the outflows.

Although all correlations found were very strong ($r > 0.90$), the best coefficients were observed in the second ($r = 0.99$), third ($r = 0.98$) and fourth ($r = 0.99$) quarters. However, the worst coefficient was observed for the first quarter ($r = 0.92$), even when compared to the yearly period ($r = 0.97$).

The correlations found between the outflows and the conventional streamflow gauge station Q2 showed, as expected, slightly lower values, compared to the correlations found for Q1, although very strong relationships were also obtained in all periods, indicating that the average values of outflows also showed a high degree of association with the flow data of the conventional downstream streamflow gauge station. For this situation, the best fits found were obtained for the second ($r = 0.96$) and fourth ($r = 0.98$) quarters and the lowest fits for the first ($r = 0.90$) and third ($r = 0.91$) quarters, being close or equal to that found for the yearly period ($r = 0.90$).

These analyses reinforce the selection of the base period for the studies (2005 to 2019) and the indication that the Q1 and Q2 data before the Queimado HPP reservoir started operating would not be adequately used, since disregarding the changes made in the flow regime due to interference caused by the construction of the dam may lead to low-quality water availability estimates, especially due to the proximity between the analyzed points.

On the other hand, the correlations found between the outflows and the conventional streamflow gauge station Q3 were significantly lower when compared with Q1 and Q2, particularly when considering the yearly period (r = 0.62), being a moderate correlation according to the classification of Bozzoni (2020).

The reduction observed between the degree of association of the outflows and the flows in Q3 demonstrates the loss of influence of the Queimado HPP reservoir's operation on the regime of variation of the average flows in this station, justified by the increase in the distance between the analyzed points. The largest reductions in correlation with Qout occurred for the first (r = 0.67) and second (r = 0.74) quarters, periods characterized by the increase in rainfall regime in the region, indicating greater influences of contributions from the drainage areas downstream of the reservoir, than effectively from its operation.

However, for the dry season, in which the contribution of surface runoff is greatly reduced, the values of correlations for the third (r = 0.88) and fourth (r = 0.84) quarters, between the average outflows and Q3 increased, although it cannot be said that the relationship between these variables is as strong as those found for the other stations.

Thus, based on the reduction observed in the correlations between Qout and Q3, the correlation between the average inflows and Q3 was also evaluated. The correlations obtained for the yearly period, 1st, 2nd and 4th quarters were equal to 0.85, 0.80, 0.88 and 0.84, respectively, being classified as strong. For the 3rd quarter, the classification was even better, with r equal to 0.94 (very strong).

In this evaluation, it is evident that the correlations observed between the flows of Q3 and inflow to the reservoir are significantly better (strong or very strong) than those observed with the outflows.

Therefore, these results indicate that the variability of the flows in this position of hydrography is influenced much more by the hydrological characteristics and land use and occupation of the basin than by the reservoir activity itself.

3.2. Trend analysis

Figure 6 shows the values of the minimum annual 7-day flow (Q_7), average annual flow (Q_{avg}) and maximum annual flow (Q_{max}) obtained over the hydrological years from 2005/2006 to 2018/2019, for the inflow and outflows of the Queimado HPP reservoir.

According to Fig. 6, it can be observed that, in general, the magnitude of the maximum inflows is greater than that of the maximum outflows. On the other hand, the minimum inflows have a lower magnitude compared to the minimum outflows, which is justified by the reservoir's regulatory activity.

It is also possible to note that the flows, especially for the last years, both inflows and outflows, have lower values for all variables when compared to the initial years of the series. This behavior could be confirmed after trend tests were applied to each series, which pointed to a decreasing trend in all flows (Table 3).

Table 3
Mann-Kendall (MK)/Modified Mann-Kendall (MMK) and Sen's Slope trend test results for the inflow and outflow Q_7, Q_{avg} and Q_{max} of the Queimado HPP reservoir

Historical Series	**Variables**	**Mann-Kendall / *Modified Mann-Kendall* (5%)**				**Sen's Slope (5%) ($m^3.s^{-1}.year^1$)**		
		p-value	**Z-value**	**Kendall's Tau**	**Trend***	**Slope**	**Upper CI**	**Lower CI**
	Q_7	*0.001*	*-3.235*	-0.516	↓	-1.009	-1.569	-0.431
Inflow	Q_{avg}	*0.002*	*3.062*	-0.626	↓	-2.993	-4.249	-1.7738
	Q_{max}	0.012	*2.518*	-0.517	↓	-7.125	-11.533	-1.866
	Q_7	0.015	2.442	-0.508	↓	-1.321	-2.314	-0.333
Outflow	Q_{avg}	*0.001*	*3.389*	-0.692	↓	-2.976	-4.132	-1.837
	Q_{max}	*0.003*	*3.058*	-0.604	↓	-10.286	-14.200	-3.400
* (↓) decreasing trend; (↑) increasing trend and (-) no trend.								

The results presented in Table 3 show the significant reduction for all inflows to the reservoir, confirming the trend observed in Fig. 6. This decreasing trend is indicative of problems for electricity generation in the Queimado HPP as well as for the other downstream uses of the dam.

For this reason, it is important to quantify the proportion of these reductions over the years, aiming to contribute to the management of current and future water availability.

The application of the Sen's Slope estimator provided the magnitude of these decreases over the years for all variables considered (Fig. 7). For the minimum flow, represented by Q_7, there have been reductions of 1.009 $m^3.s^{-1}$ per year for inflows and 1.321 $m^3.s^{-1}$ per year for the outflows.

These results indicate that, although the reservoir regularized the flows downstream of the dam, the values of outflows are directly influenced by the characteristics of the inflows, so the most significant reductions found in the outflows may be associated with greater need for water conservation in the reservoir in order to ensure supply in the dry season.

For the average flows, there were very similar annual reductions, around 2.993 $m^3.s^{-1}$ and 2.976 $m^3.s^{-1}$ for inflows and outflows, respectively, indicating that the water availability of the basin, as well as its potential for electricity generation, is being reduced over time.

When analyzing the maximum flows, the results indicated that the decreases recorded for the outflows over the years are higher than those found for the inflows, so that, downstream of the reservoir, the flows decrease by 10.286 $m^3.s^{-1}$ per year, while the inflows showed annual reductions of 7.125 $m^3.s^{-1}$.

The difference between these results is expected due to the regularization promoted by the reservoir, retaining the flows of greater magnitudes in the rainy season and then releasing them in the dry season. Thus, the maximum flows passing through the dam are subject to the operational control of the plant, in such a way that part is retained and part is made available downstream.

Table 4 shows the results of trend analyses for conventional ANA stations located downstream of the Queimado HPP reservoir.

Table 4
Mann-Kendall (MK)/Modified Mann-Kendall (MMK) and Sen's Slope trend test results for Q_7, Q_{avg} and Q_{max} flows of stations Q1, Q2 and Q3 located downstream of the Queimado HPP reservoir

Historical Series	Variables	Mann-Kendall / Modified Mann-Kendall (5%)				Sen's Slope (5%) ($m^3.s^{-1}.year^1$)		
		p-value	**Z-value**	**Kendall's Tau**	**Trend***	**Slope**	**Confidence Interval**	
							Upper	**Lower**
Q1	Q_7	0.028	2.197	-0.451	↓	-1.111	-1.928	-0.112
	Q_{avg}	0.000	3.504	-0.714	↓	-3.072	-4.384	-1.983
	Q_{max}	0.004	2.847	-0.582	↓	-11.129	-17.496	-4.286
Q2	Q_7	0.021	2.299	-0.472	↓	-1.490	-3.201	-0.267
	Q_{avg}	0.000	3.832	-0.780	↓	-4.270	-5.958	-2.668
	Q_{max}	0.000	4.911	-0.648	↓	-17.825	-27.670	-11.098
Q3	Q_7	0.012	2.518	-0.516	↓	-2.917	-4.266	-1.028
	Q_{avg}	0.000	3.504	-0.714	↓	-8.689	-10.514	-5.410
	Q_{max}	0.324	0.985	-0.209	-	-	-	-

* (↓) decreasing trend; (↑) increasing trend and (-) no trend.

The series of minimum, average and maximum flows for stations Q1 and Q2 also showed decreasing trends, which demonstrates the influence of reservoir operation in these monitoring sections. The minimum flows in Q1 and Q2 showed reductions of -1.111 and − 1.490 $m^3.s^{-1}.year^{-1}$, respectively, close to those verified for the inflows and outflows of the Queimado HPP reservoir. For the average and maximum flows of stations Q1 and Q2, the magnitudes of the annual reductions found increased as the drainage area of the stations increased, so the decreases found for Q2 were higher, with average flows reducing by 4.270 $m^3.s^{-1}.year^{-1}$ and maximum flows reducing by 17.825 $m^3.s^{-1}.year^{-1}$.

In Q3, the farthest station from the reservoir, the minimum flows showed reductions of 2.917 $m^3.s^{-1}.year^{-1}$ and the average flows showed reductions of 8.689 $m^3.s^{-1}.year^{-1}$. This station has an increase in the drainage area of about 60% in relation to the position of the reservoir. This may probably explain the greater reduction of minimum and average flows in this station compared to Q1 and Q2, since there will be greater variability regarding soil type, geomorphology and, also, water demand for irrigation. However, for the maximum flows, no trend was identified, thus characterizing them as stationary throughout the analyzed period.

Given the reductions in the flows (minimum, average and maximum) observed in the present study, statistical trend analyses were also applied for the rainfall series of the stations used in the study (Table 5) to evaluate whether the reductions were being influenced by the climatic behavior of the region.

Table 5
Mann-Kendall (MK)/Modified Mann-Kendall (MMK) trend test results for rainfall data series of the selected stations in the Preto River Basin

Stations (Code)	Total Annual Rainfall			
	p-value	Z-value	Kendall's Tau	Trend
01546005**	0.721	0.358	-0.111	-
01547003	0.228	1.204	-0.253	-
01547004**	0.381	0.876	-0.187	-
01547009**	0.858	0.179	-0.067	-
01547013**	0.428	0.793	-0.179	-
01547014**	0.246	1.159	-0.256	-
01547017**	0.721	0.358	-0.111	-
01547018**	1.000	0.000	0.011	-
01547021	0.324	0.985	-0.209	-
01547022	0.742	0.328	-0.077	-
01645019**	0.047	1.989	-0.455	↓
01646000	0.742	0.328	-0.077	-
01646001	0.079	1.752	-0.362	-
01646003	0.661	0.438	-0.099	-
01646004	0.127	1.525	-0.333	-
01647008	0.194	1.556	-0.382	-
01746001**	0.101	1.642	-0.341	-
01746002**	0.033	2.135	-0.461	↓
01746017**	0.033	2.135	-0.461	↓
* (↓) decreasing trend; (↑) increasing trend and (-) no trend.				
** Stations located around the Preto River Basin				

Rainfall variability within the period considered, in general, was stationary for the annual period, indicating that the rain did not show significant changes over the years. Only three stations indicated significant changes in total annual rainfall, the codes of which are 01645019, 01746002 and 01746017. All these stations are located near the mouth, outside the boundaries of the basin, which indicates that the reductions in flows in the upstream positions of the basin do not have considerable influence of the rainfall behavior and, therefore, it is not possible to affirm that the behavior of rainfall in these positions is responsible for reducing the inflow and outflows of the Queimado HPP reservoir and in the Q1 and Q2 stations.

Thus, the results show that the reduction of flows cannot be associated with the variation of the annual rainfall regime, opening precedents for a possible preponderance of anthropic activities over climatic conditions, since the Preto River Basin is a frontier of agricultural expansion with marked use of irrigation.

These findings corroborate those obtained by Xue et al. (2017), who observed that human activities played a dominant role in reducing the flows of the Tarim River, when compared with the climatic variables, as well as those obtained by Gao et al. (2011), who also identified that the contributions of human activities were significantly stronger for the reductions in flow than rainfall in the Yellow River Basin in China.

Machado and Netto (2010) mentioned that in the Preto River Basin, located within the territory of the Federal District, there was a dominance of agricultural activities with pronounced use of center pivots for irrigation, which already contributed to the reduction of water availability, especially in the dry season. In their study, the authors identified that by 2007 there were 207 center pivots, representing 17,620 hectares of irrigated land along the entire length of the basin, with higher concentrations in the northwest region.

ANA, in partnership with Embrapa, mapped the number of center pivot irrigation equipment in Brazil between 1985 and 2019. Based on the period considered by this study (2005 to 2019), in the Preto River Basin, the number of pivots showed a very significant growth. In 2010, the number of center pivots recorded was 370 units, with an irrigated area of 28,539.9 hectares, increasing in 2014 to 556 units, which represented an increase of 33.6% in the irrigated area (42,979.8 hectares). In 2017, the mapping identified the presence of 682 center pivots distributed throughout the basin, whose implementation increased the irrigated area to 49,087.3 hectares. In 2019, the total number of pivots recorded became 786 units, 53% more than in 2010, and 488 of these were concentrated in the northwest region of the basin (ANA, 2021).

Thus, despite the noticeable growth of center pivot irrigation activity in the Preto River Basin, Fig. 8 shows that these equipments are more markedly concentrated in the source regions, upstream of the Queimado HPP reservoir.

The sharp increase in the number of center pivots in the Preto River Basin may represent a significant portion of the reductions of flows over the years, especially for those that flow into the Queimado HPP reservoir, thus impacting all other activities influenced by it.

Associated with the increase in the number of pivots in the basin, conflicts over water use have been taking on greater proportions over the years, especially in the dry season, requiring mediation by the management bodies. According to Maniçoba (2019), the area of the Preto River Basin Committee of the Federal District (*Comitê de Bacia Hidrográfica do Preto do Distrito Federal* - CBH Preto - DF) is irrigated for grain production and has water conflicts that have been dealt with in negotiated allocation meetings.

In 2016, ANA, through Resolution No. 934, authorized the reduction of the minimum discharge of the Queimado HPP reservoir, considering the importance of preserving the available water stock and also mentioning the unfavorable hydrometeorological situation for the upstream section of the reservoir. The reduction of the minimum outflow went from 17 $m^3.s^{-1}$ to 10 $m^3.s^{-1}$, being allowed only between August and October of that year.

Although the resolution mentions the hydrometeorological crisis at that time, it is important to remember that the irrigated area almost tripled from 2007 to 2017 and still remains constantly expanding, so management difficulties have already become a reality of the basin.

It is also interesting to mention that small reservoirs play an important role in supporting the local economy and are mainly used for supplying of water for irrigation and cattle watering (Althoff et al. 2019). In the Preto River Basin, a survey conducted by Rodrigues et al. (2012) identified the presence of 147 of these small dams, with a surface area between 1 and 50 ha. According to the authors, the portions of the Federal District and Goiás located within the Preto River Basin, considered in this study as the most representative for the area upstream of the Queimado HPP reservoir, had the capacity to store, respectively, 14% (one every 30 km^2 – 44 reservoirs) and 29% (one every 70 km^2 – 32 reservoirs) of the water of the basin in these structures. Nevertheless, records of grants were found, between 2011 and 2019, for only 30 of these units considering the analysis of the same region, according to information available on the platform of the Water, Energy and Sanitation Regulatory Agency of the Federal District (*Agência Reguladora de Águas, Energia e Saneamento do Distrito Federal* - ADASA).

This information draws attention to the fact that the presence of these small dams, aimed at increasing water availability in certain segments of the basin, may also be contributing to the reduction of inflows to the Queimado HPP reservoir, especially with regard to maximum flows.

4. Conclusions

- The strong correlation between inflow and outflows of the Queimado HPP reservoir indicates the high level of importance of the inflows for the operationalization of the reservoir, and the best results were obtained when considering, in the vast majority, quarterly data intervals.
- The variation in the average flows of stations Q1 and Q2 is strongly dependent on the average outflows of the reservoir, while the variation in the average flows of station Q3, located farther from the reservoir, is less influenced by the operation of the reservoir and more dependent on the hydrological behavior of the basin and the advance of activities related to the use of water resources (e.g. irrigation).
- All flows analyzed (Q7, Qavg and Qmax), both inflow and outflow from the Queimado HPP reservoir, showed a decreasing trend from 2005 to 2019.
- The conventional streamflow gauge stations located downstream of the Queimado HPP reservoir (Q1, Q2 and Q3) show a decreasing trend for all analyzed flows (Q_7, Q_{avg} and Q_{max}), except for the one located farther away (Q3), in which no trend was observed for Q_{max}.
- Total annual rainfall show no trend for most rainfall stations used for analysis of the Preto River Basin, so the reductions found in the inflows, outflows and conventional stations cannot be attributed to this variable based on the rainfall data used.

- The reductions observed in the inflows and outflows of the Queimado HPP reservoir, as well as in the stations located downstream, may be related to the increase of almost three times in the area irrigated by center pivot in the Preto River Basin in the period between 2005 and 2019, especially upstream of the Queimado HPP reservoir, giving a strong indication for of compromised flows along the hydrography.

Declarations

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Authors Contributions All authors contributed to the study conception and design. Material preparation, data collection and analysis were performed by Tarcila Neves Generoso, Demetrius David da Silva, Lineu Neiva Rodrigues, Ricardo Santos Silva Amorim and Laura Thebit de Almeida. The first draft of the manuscript was written by Tarcila Neves Generoso and all authors commented on previous versions of the manuscript.

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Ethical Approval Authors agreed to the ethical approval needed to publish this manuscript

Consent to Participate Authors have consent to participate in the publication process.

Consent to Publish Authors agreed to publish this manuscript

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References

1. Abeysingha, N. S., Singh, M., Sehgal, V. K., Khanna, M., Pathak, H. (2016). Analysis of trends in streamflow and its linkages with rainfall and anthropogenic factors in Gomti River basin of North India. Theor Appl. Climatol, 123:785-799. https://doi.org/10.1007/s00704-015-1390-5
2. Althoff, D., Rodrigues, L. N., Silva, D. D. da., Bazame, H. C. (2019). Improving methods for estimating small reservoir evaporation in the Brazilian Savanna. Agric. Water Manag, 2016: 105-112. https://doi.org/10.1016/j.agwat.2019.01.028.
3. Agência Nacional de Águas e Saneamento Básico – ANA. (2021). Atlas Irrigação: Uso da água na agricultura irrigada. 2ª ed. Brasília. 130p.
4. Back, A. J. (2001). Aplicação de análise estatística para identificação de tendências climáticas. Pesqui. Agropecu. Bras., 36:717-726. https://doi.org/10.1590/S0100-204X2001000500001
5. Bozzoni, P.L., Mello Junior, A.V. (2020). Previsões de precipitação de modelos atmosféricos como subsídio à operação de sistemas de reservatório. Rev. Bras. de Meteorol., 35:99-109. http://dx.doi.org/10.1590/0102-778635103
6. Busker, T., Roo, A. de., Gelati, E., Schwatke, C., Adamovic, M., Bisselink, B., Pekel, J-F., Cottam, A. (2019). A global lake and reservoir volume analysis using a surface water dataset and satellite altimetry. Hydrol. Earth Syst. Sci., 23:669-690. https://doi.org/10.5194/hess-23-669-2019
7. Chang, L.-C., Chang, F.-J. (2001). Intelligent control for modelling of real-time reservoir operation. Hydrol Process, 15:1621–1634. https://doi.org/10.1002/hyp.226
8. Dubey, S. K., Sharma, D., Babel, M. S., Mundetia, N. (2020). Application of hydrological model for assessment of water security using multi-model ensemble of CORDEX-South Asia experiments in a semi-arid river basin of India. Ecol. Eng., 143, 105641. http://doi.org/10.1016/j.ecoleng.2019.105641
9. Ferrari, A. L. (2012). Variabilidade e tendência da temperatura e pluviosidade nos municípios de Pirassununga, Rio Claro, São Carlos e São Simão (SP): Estudo sobre mudança climática de curto prazo em escala local. Tese. Universidade de São Paulo-USP. São Carlos/SP, 156 p.
10. Gao, L., Mu, X. M., Wang, F., Li, R. (2011). Changes in streamflow and sediment discharge and the response to human activities in the middle reaches of the Yellow River. Hydrol. Earth Syst. Sci., 15:1-10. https://doi.org/10.5194/hess-15-1-2011
11. Hamed, K. H., Rao, R. (1998). A modified Mann-Kendall trend test for auto-correlated data. J. Hydrol., 204:182-196. https://doi.org/10.1016/S0022-1694(97)00125-X
12. Helsel, D. R., Hirsch, R. M. (2002). Statistical methods in water resources. U.S. Geological Survey. 522 p.
13. Helsel, D. R., Hirsch, R. M., Ryberg, K. R., Archfield, S. A., Gilroy, E. J. (2020). Statistical methods in water resources: U.S. Geological Survey Techniques and Methods, book 4, chapter A3, 458 p. https://doi.org/10.3133/tm4a3

14. Hirsch, R. M., Slack, R. J., Smith, R. (1982). Techniques of trend analysis for monthly water quality data. Water Resour. Res., 18:107-121. https://doi.org/10.1029/WR018i001p00107
15. Kendall, M. G. (1975). Rank Correlation Methods. Charles Griffin, London.
16. Maniçoba, A. M. (2019). Um modelo de gestão participativa: o uso compartilhado de recursos hídricos na Unidade Hidrográfica do Ribeirão Extrema – DF. Dissertação de Mestrado – Pós-Graduação em Saúde Pública, Fundação Oswaldo Cruz. Brasília-DF
17. Mann, H. B. (1945). Nonparametric tests against trend. Econometrica 13, 245-259.
18. Machado, N. D. S., Netto, O. M, C. (2010). Análise econômica aplicada à decisão sobre alocação de água entre os usos irrigação e produção de energia elétrica: o caso da bacia do rio Preto (DF/GO/MG). Ver. Bras. Recur. Hídr., 15:105-119. http://doi.org/ 10.21168/rbrh.v15n4.p105-119
19. Neeti, N., Eastman, J. R. (2011). A Contextual Mann-Kendall Approach for the Assessment of Trend Significance in Image Time Series. Transactions in GIS, 15:599-611. https://doi.org/10.1111/j.1467-9671.2011.01280.x
20. Nourani, V., Rouzegari, N., Molajou, A., Baghanam, A. H. (2020). An integrated simulation-optimization framework to optimize the reservoir operation adapted to climate change scenarios. J. Hydrol., 587. doi: https://doi.org/10.1016/j.jhydrol.2020.125018.
21. Organização Meteorológica Mundial – OMM. (1975). Drought and agriculture. WMO Tech. Note 138, Publ. WMO-392, Geneva, Switzerland, 127p.
22. Organização Meteorológica Mundial – OMM. (1988). Analyzing long timeseries of hydrological data with respect to climate variability. Wcap-3, WMO/TD 224.
23. Operador Nacional do Sistema Elétrico – ONS. (2020). Plano de Operação Energética 2020/2024. Available at: < REVISTA_PEN 2020_versao20201112.pdf (ons.org.br)>, access on May 17, 2021.
24. Operador Nacional do Sistema Elétrico – ONS. (2020). Manual de procedimentos de operação: Módulo 5 – Submódulo 5.12. Available at: < http://www.ons.org.br/%2FMPO%2FDocumento%20Normativo%2F3.%20Instru%C3%A7%C3%B5es%20de%20Opera%C3%A7%C3%A3o%20-%20SM%205.12%2F3.6.%20Opera%C3%A7%C3%A3o%20de%20Reservat%C3%B3rios%2FIO-OR.SF.SFR_Rev.23.pdf> Access on: May 18, 2021.
25. Passaia, O. A., Paiva, R. C. D. (2019). Análise exploratória do comportamento de reservatórios do sistema interligado nacional. XXIII Simpósio Brasileiro de Recursos Hídricos. Foz do Iguaçu.
26. Pereira, G., Cardozo, F. da S., Negreiros, A. B. de., Zanin, G. D., Costa, J. C. da., Lima, T. E. R., Rufino, P. R., Ramos, R. de C. (2018). Análise da variabilidade da precipitação para o estado de minas gerais (1981-2017). RBClima. doi: http://dx.doi.org/10.5380/abclima.v1i0.61028
27. Rippl, W. (1883). The capacity of storage-reservoirs for water-supply. Proc. Inst. Civil Engrs, 71:270-278.
28. Rodrigues, L. N., Sano, E. E., Steenhuis, T. S., Passo, D. P. (2012). Estimation of small reservoir storage capacities with remote sensing in the Brazilian Savannah region. Water Resour. Manage., 26:873-882. doi: 10.1007/s11269-011-9941-8.
29. Salviano, M. F., Groppo, J. D., Pellegrino, G. Q. (2016). Análise de Tendências em Dados de Precipitação e Temperatura no Brasil. Rev. Bras. Meteorol,, 31:64–73. https://doi.org/10.1590/0102-778620150003
30. Schaefli, B. (2015). Projecting hydropower production under future climates: a guide for decision-makers and modelers to interpret and design climate change impact assessments. Wiley Interdiscip. Ver.: Water, 2:271–289. https://doi.org/10.1002/wat2.1083
31. Silva, F. B., Almeida, L. T. de., Vieira, E. O. de., Silva, D. D. da, Maciel, I. P., Parma Júnior, F. (2020). Pluviometric and fluviometric trends in association with future projections in areas of conflict for water use. J. Environ. Manage., 271. https://doi.org/10.1016/j.jenvman.2020.110991
32. Silva, R. M. da., Santos, C. A. G., Moreira, M., Corte-Real, J., Silva, V. C. L., Medeiros, I. C. (2015). Rainfall and river flow trends using Mann–Kendall and Sen's slope estimator statistical tests in the Cobres River basin. Nat. Hazards, 77:1205–1221. https://doi.org/10.1007/s11069-015-1644-7
33. Sen, P. K. (1968). Estimates of the regression coefficient based on Kendall's Tau. J. Am. Stat. Association, 63:1379-1389.
34. Shadkam, S., Ludwig, F., van Oel, P., Kirmit, Ç., Kabat, P. (2016). Impacts of climate change and water resources development on the declining inflow into Iran's Urmia Lake. J. Great Lakes Res., 42: 942–952. doi:10.1016/j.jglr.2016.07.033
35. Spalding-Fecher, R., Chapman, A., Yamba, F., Walimwipi, H., Kling, H., Tembo, B., Nyambe, I., Cuamba, B. (2014). The vulnerability of hydropower production in the Zambezi River Basin to the impacts of climate change and irrigation development. Mitig. Adapt. Strateg. Glob. Chang, 19:1–22. https://doi.org/10.1007/s11027-014-9619-7
36. Setti, A. A., Lima, J. E. F. W., Chaves, A. G. de M., Pereira, I. de C. (2000). Introdução ao gerenciamento de recursos hídricos. Agência Nacional de Energia Elétrica, Superintendência de Estudos e Informações Hidrológicas. 2ª Ed. Brasília. 207p.
37. Tucci, C. E. M., Braga, B. (2003). Clima e Recursos Hídricos no Brasil. Porto Alegre: ABRH.
38. Wu, J., Liu, Z., Yao, H., Chen, X., Chen, X., Zheng, Y., He, Y. (2018). Impacts of reservoir operations on multi-scale correlations between hydrological drought and meteorological drought. Journal of Hydrology, 563:726–736. https://doi.org/10.1016/j.jhydrol.2018.06.053

39. Xue, L., Yang, F., Yang, C., Chen, X., Zhang, L., Chi, Y., Yang, G. (2017). Identification of potential impacts of climate change and anthropogenic activities on streamflow alterations in the Tarim River Basin, China. Sci. Rep., 7. https://doi.org/10.1038/s41598-017-09215-z
40. Yue, S., Pilon, P., Cavadias, G. (2002). Power of the Mann-Kendalland Spearman's rho tests for detecting monotonic trends in hydrological series. J. Hydrol., 259:254-271. https://doi.org/10.1016/S0022-1694(01)00594-7

Figures

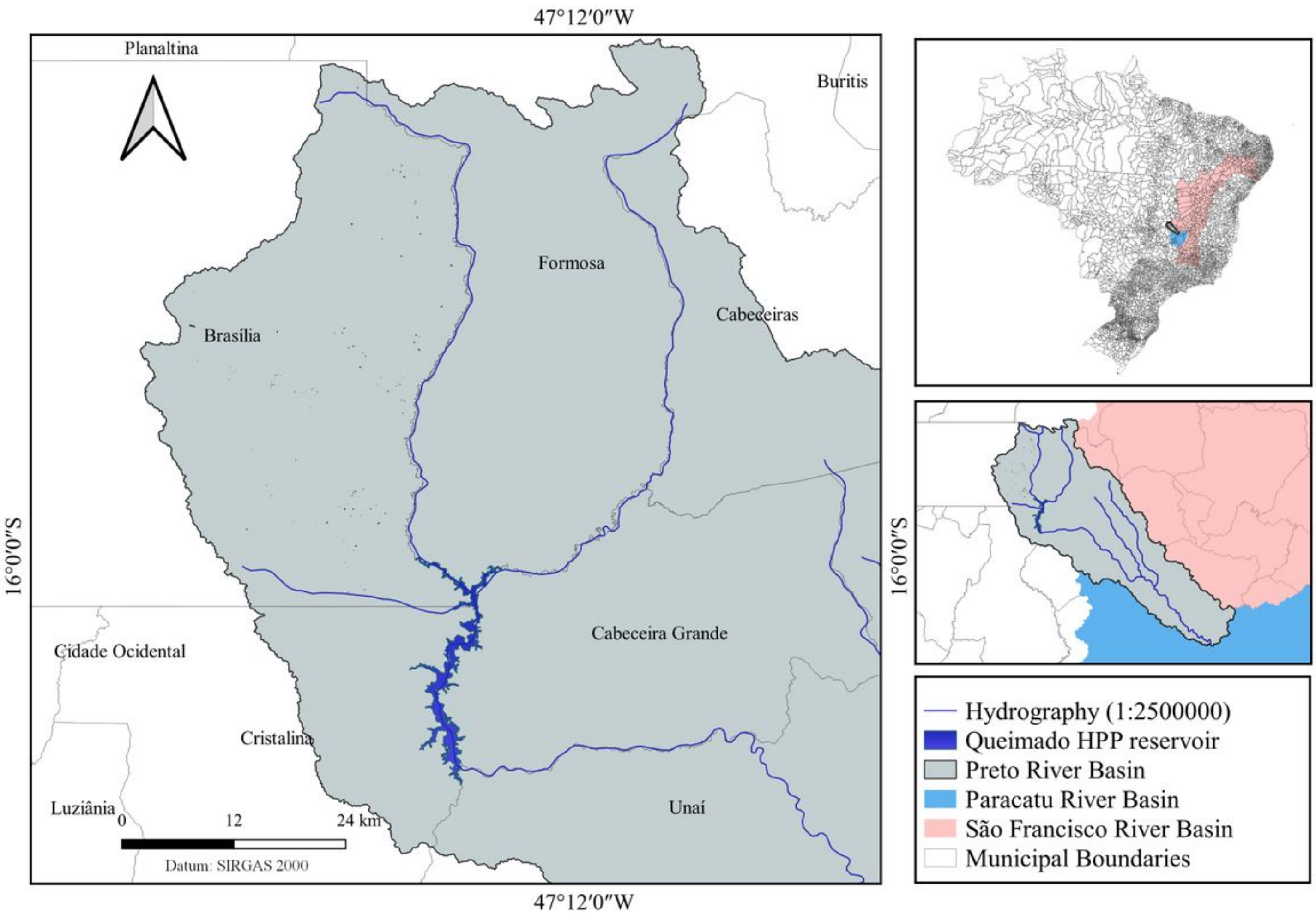

Figure 1

Location of the Queimado HPP reservoir

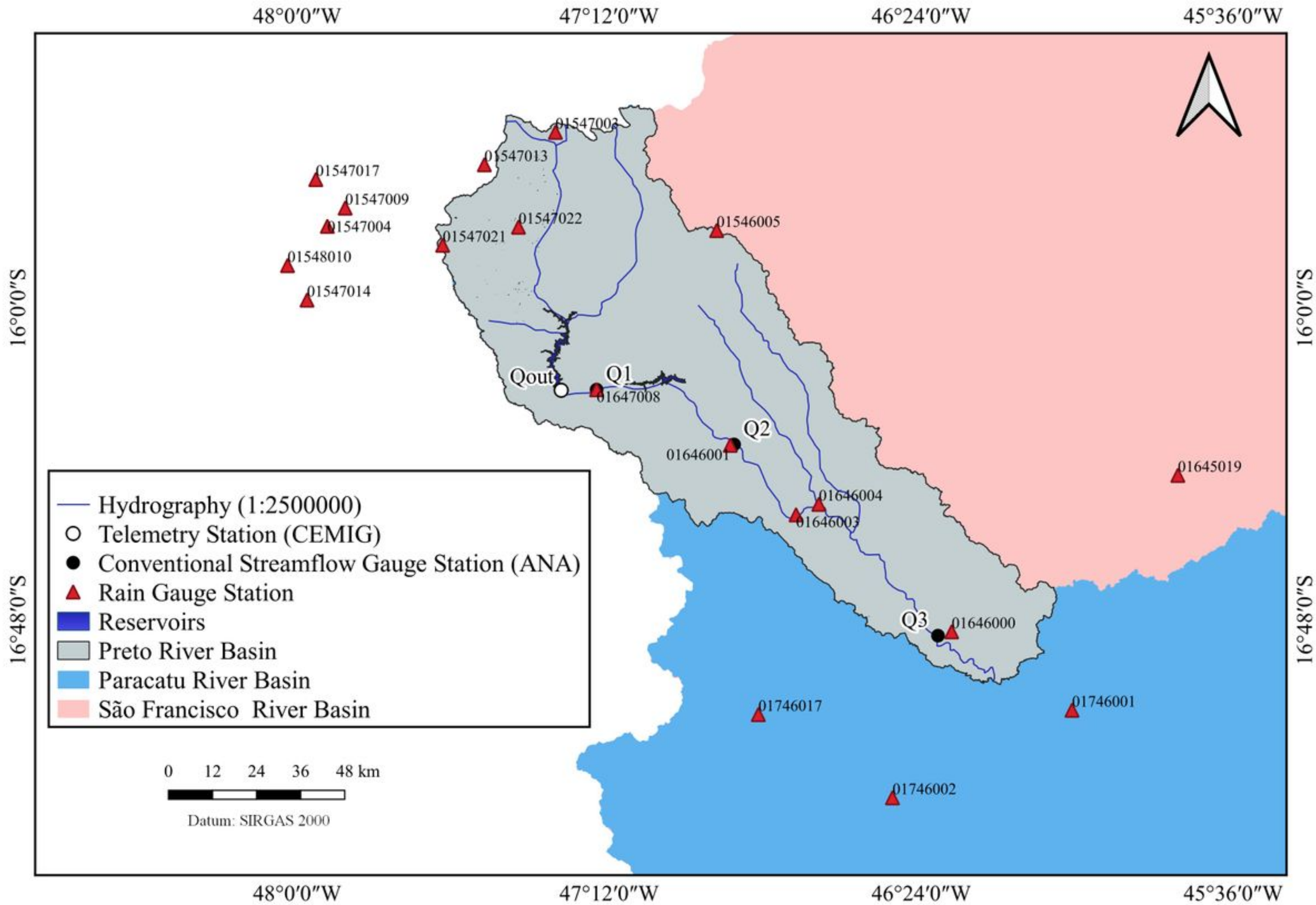

Figure 2

Location of the streamflow and rain gauge stations of the ANA hydrometeorological network selected for the study in the Preto River Basin and the outflow telemetry station of the Queimado HPP reservoir

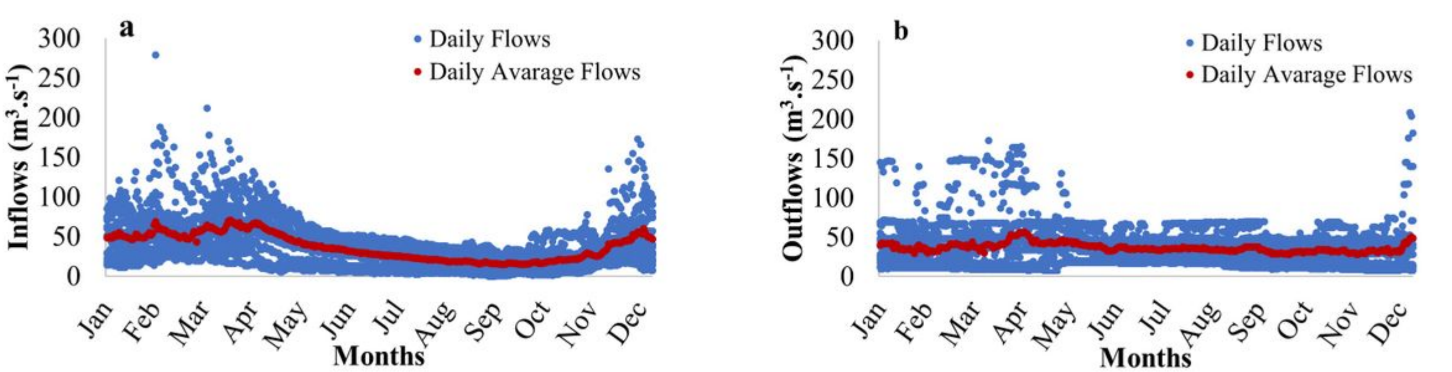

Figure 3

Daily inflows (a) and outflows (b) of the Queimado HPP reservoir between 2005 and 2019

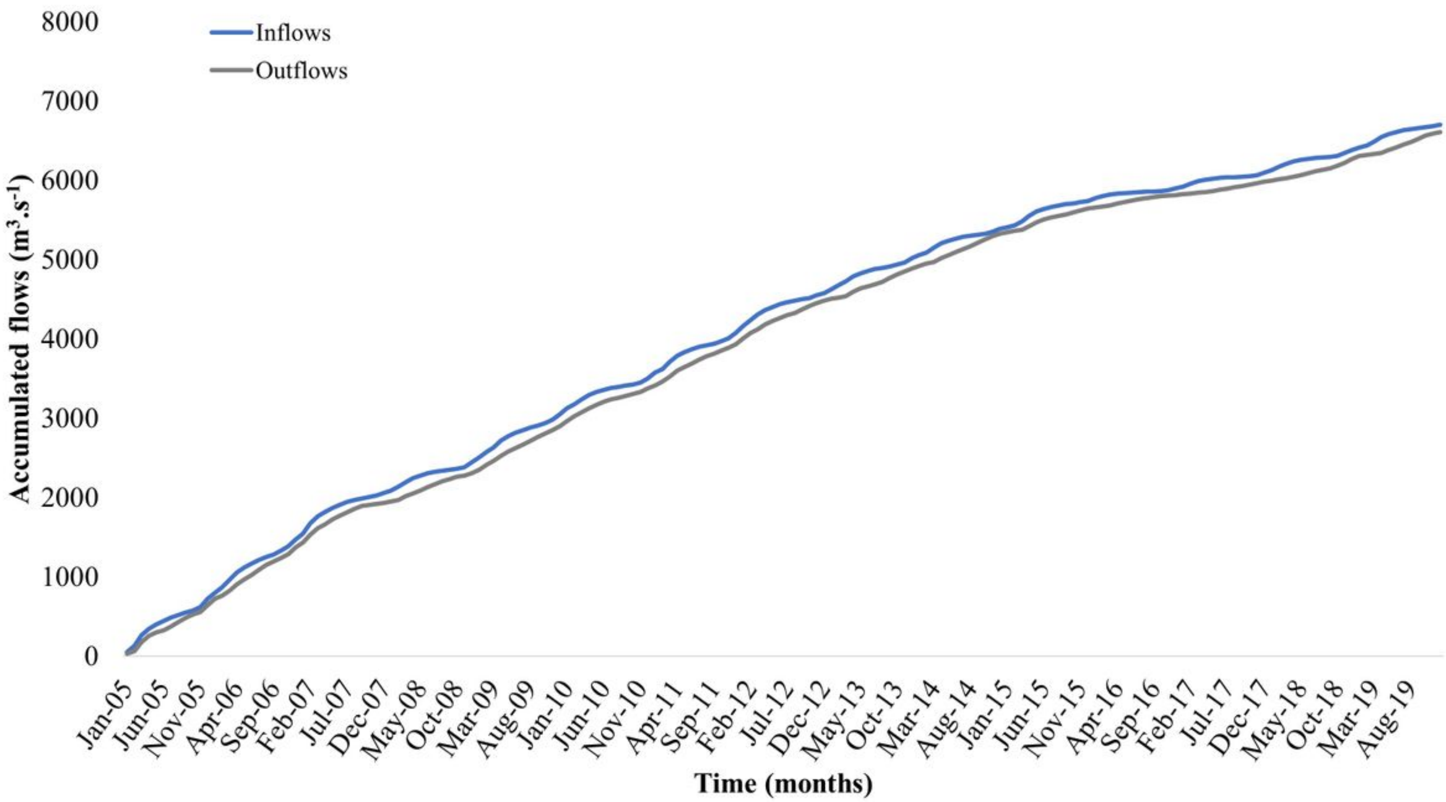

Figure 4

Mass diagram of inflows and outflows of the Queimado HPP reservoir

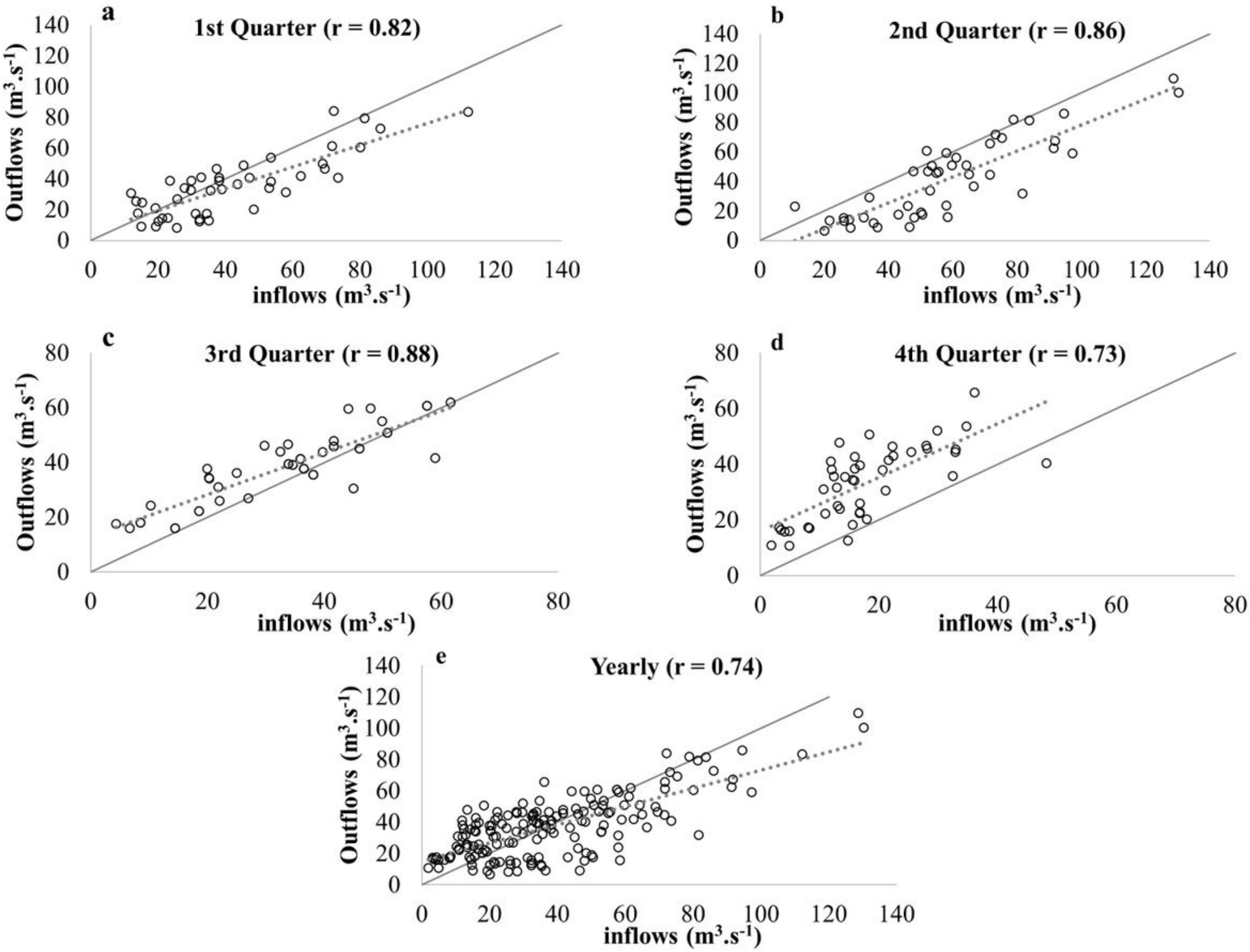

Figure 5

Correlations obtained between the inflows and outflows of the Queimado HPP reservoir on the quarterly (a, b, c and d) and yearly (e) scales, over the period from 2005 to 2019

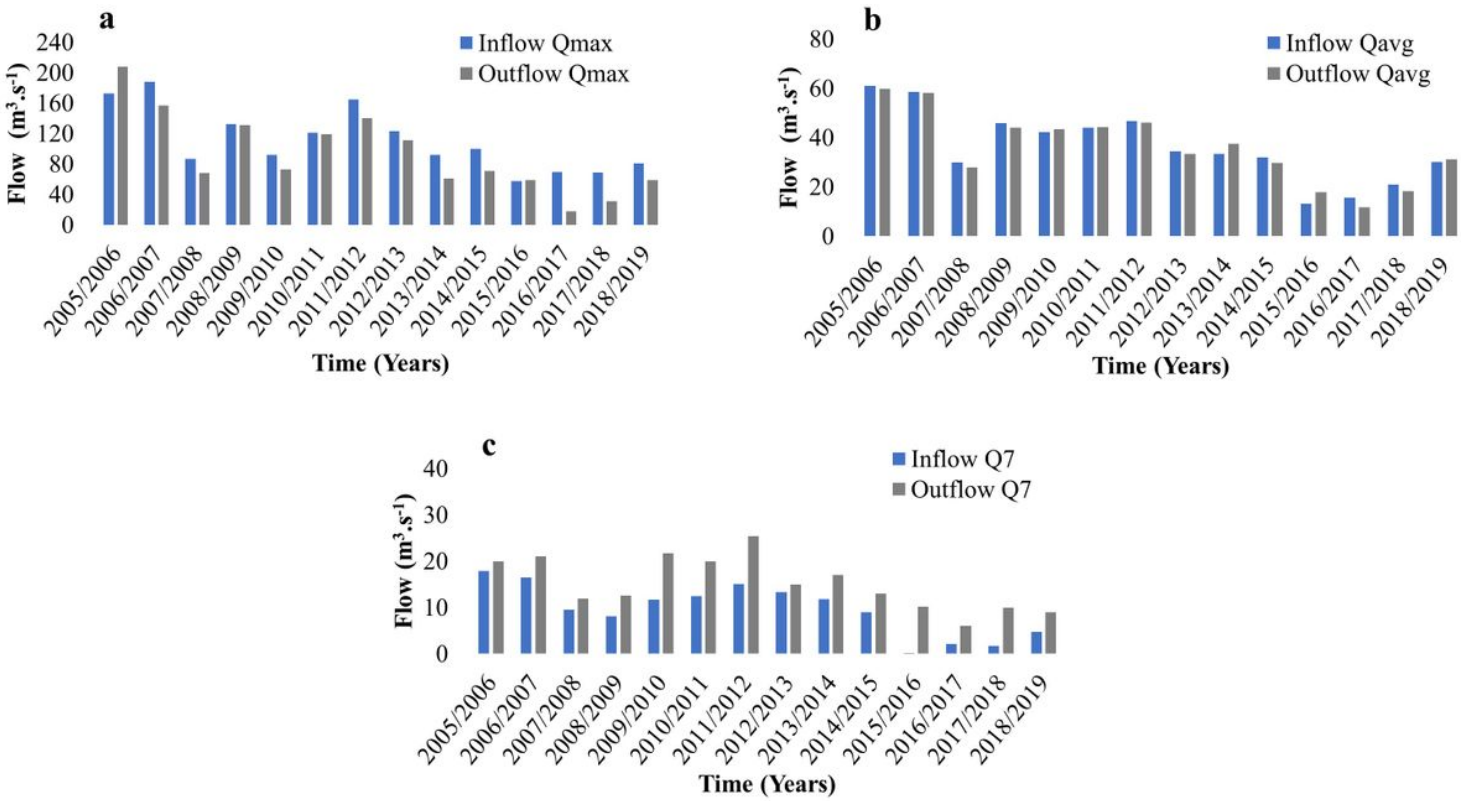

Figure 6

Values of maximum annual daily flow (Q_{max}) (a), average annual flow (Q_{avg}) (b) and minimum 7-day flow (Q_7) (c), inflows and outflows of the Queimado HPP Reservoir, from 2005/2006 to 2018/2019

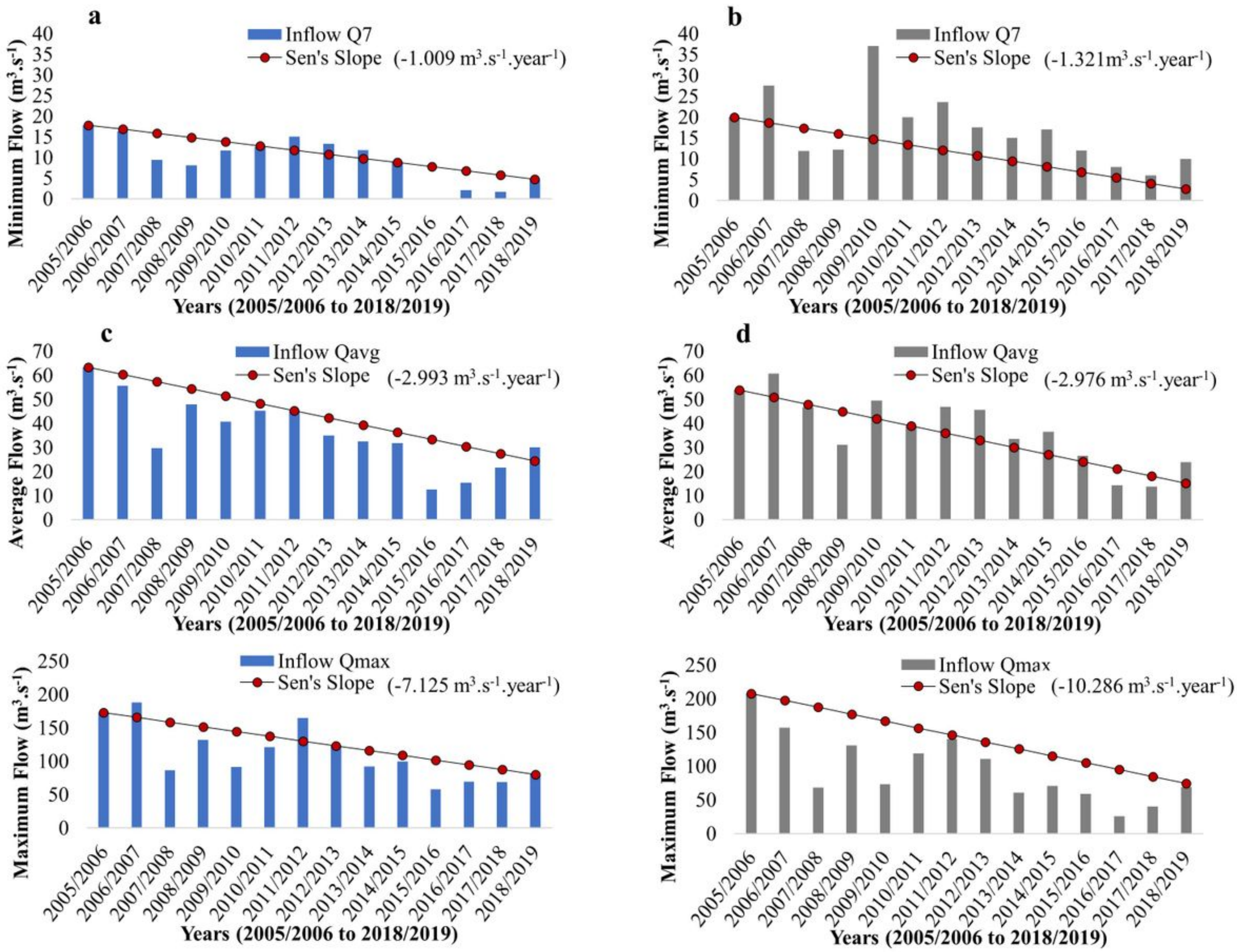

Figure 7

Inflow (a, c and e) and outflow (b, d and f) Q_7, Q_{avg} and Q_{max} of the Queimado HPP reservoir and trend of the reductions expressed by the Sen's Slope estimator, from 2005/2006 to 2018/2019

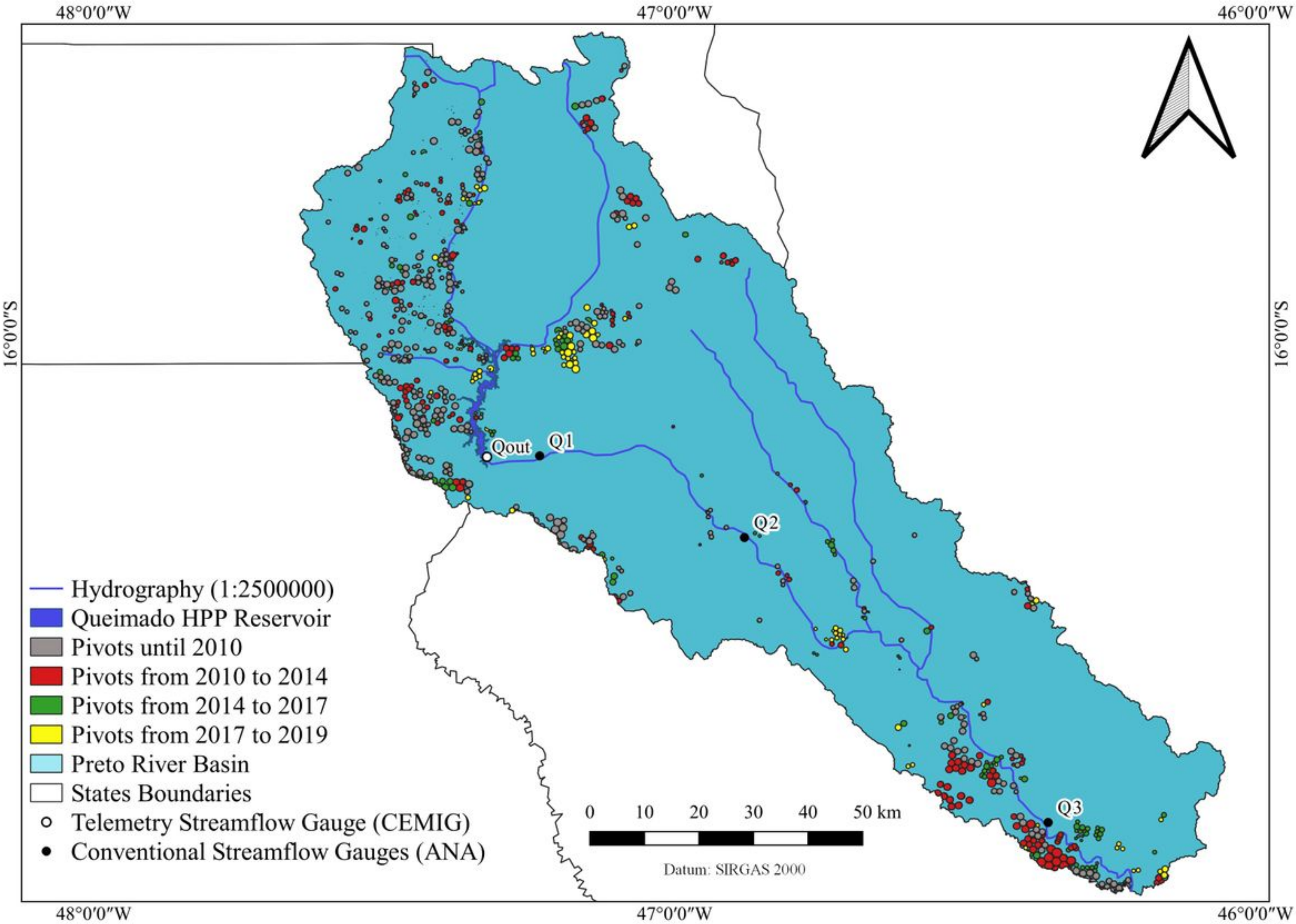

Figure 8

Distribution of center pivots in the Preto River Basin for the years 2010, 2014, 2017 and 2019