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Water Availability Assessment from Power Generation Reservoirs in the Rio Grande Operated by Furnas, Brazil

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Abstract: Analyzing water availability from energy generation reservoirs is a determining factor in inferring the economic and development capacity of countries that operate primarily with hydroelectric generation. This is because the reservoirs configure the battery of this type of electric power generation system. In this context, the main interference variables are climate, consumptive use, operation, land use and occupation, topography, sediment input and geology. The present article analyzed rainfall data and the consumptive uses of five hydroelectric plants in the Rio Grande, operated by Furnas in Brazil. These two variables are chosen due to the frequent correlation between the rainfall regime and reservoir level and the scarcity of studies considering the influence of consumptive uses in this storage process. Data from 1994 to 2021 were analyzed from publicly available sources. The information was treated using the Mann–Kendall trend test. Having obtained the results, it was observed that there is a difference in behavior between accumulation and run-of-river plants, the rainfall regime over the years analyzed showed no trend, while the consumptive uses tend to grow. This shows the need for policies that encompass the combination of multiple uses so that the reservoirs are sustainable.

Keywords: reservoir; consumptive uses; hydroelectric plants; water capacity

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1. Introduction

The development of a nation essentially depends on the supply and conditions of the generation and transmission of electric energy. Limitations in this area broadly impact the productive sector, from basic crops to cutting-edge technology areas.

The current diversity of possibilities in a renewable generation has contributed to the energy supply, but the limitations, especially in the storage area, still require care. In this regard, hydroelectric generation is of the utmost importance as it can maintain constant energy at any time of the year, and with high generation capacity, few sources currently manage to match this.

In other countries, such as South Korea, hydroelectric reservoirs have contributed to both flood control and electricity generation by operating dams within the limited water level during flood seasons. Under such limited operations, energy loss would be unavoidable. In this case, the concept of resilience for application in the operation of a hydroelectric reservoir can be introduced to minimize such energy losses [1].

Ethiopia's energy matrix is dominated by hydroelectric generation, which largely depends on water resources and availability. Ref. [2] analyzed how power generation and CO_2 emissions would change in the future if reservoir capacity were to be halved due to drought. The results showed how a prolonged drought would reduce river flows and lead to an energy transition that may require installing other concomitant alternative plants.

Ref. [3] presented changes in the capacity of 47 reservoirs in Poland that are key objects of protection against hydrological floods and drought. Since the beginning of the operation (average operating time of 48 years), the capacity has decreased by around 5%, which means that almost 200 million m^3 less water is stored.

In this context, Brazil, which holds 12% of the world's available fresh water, plays a leading role, and hydroelectric generation plays a fundamental role, accounting for approximately 55% of the national supply [4]. An intriguing fact is that, even so, the country is on the verge of contingency in terms of energy use, as rarely does the level of its reservoirs fluctuate considerably, in strategic regions, especially during the annual drought season.

This oscillation can be seen in Figure 1, where a historical series is illustrated, from 2000 to 2022, with stored energy data (SED), generated from the National System Operator (NSO) database [5], from three of the main reservoirs implemented in Rio Grande (MG/Brazil): Furnas, Mascarenhas de Moraes and Marimbondo. The SED is associated with the volume of water available in the reservoirs that can be converted into electricity generation.

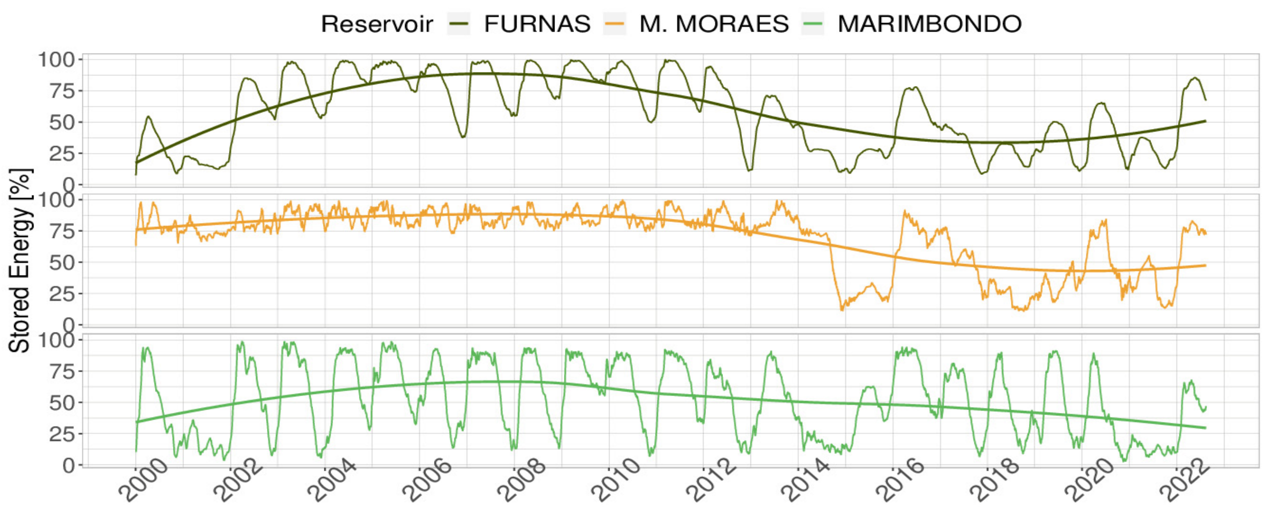

Figure 1. Stored Energy (STE)—Historical Series of Furnas, Mascarenhas de Moraes and Marimbondo Hydroelectric Power Plants (HPPs).

Processing the same database [5], but considering all the subsystems (southeast/midwest, northeast, south and north) that have comprised the National Interconnected System (NIS), since 2000, Figure 2 was made, which shows the historical rationing known as the "blackout" of 2001. During this period, Brazil went through great adversities due to the low rates in the volumes of its main reservoirs. It can be seen that in 2021, the country was at a critical level of SED, well below its maximum capacities.

For the sake of comparison, a representative curve of the installed generation capacity data [6] was added to the graph in Figure 2 in this same period, between 2000 and 2022, also considering all hydroelectric generation subsystems in Brazil. The installed generation capacity is related to the maximum power an electric power plant can generate. It can be observed that although relevant investments in hydroelectric plants were made from 2000 onwards in Brazil, the percentage of SED did not follow these numbers, mainly from 2007, when the trend of growth of the curve was reversed. This leads us to conclude that the isolated investment in the construction of new plants may not be enough to supply a growing electricity demand.

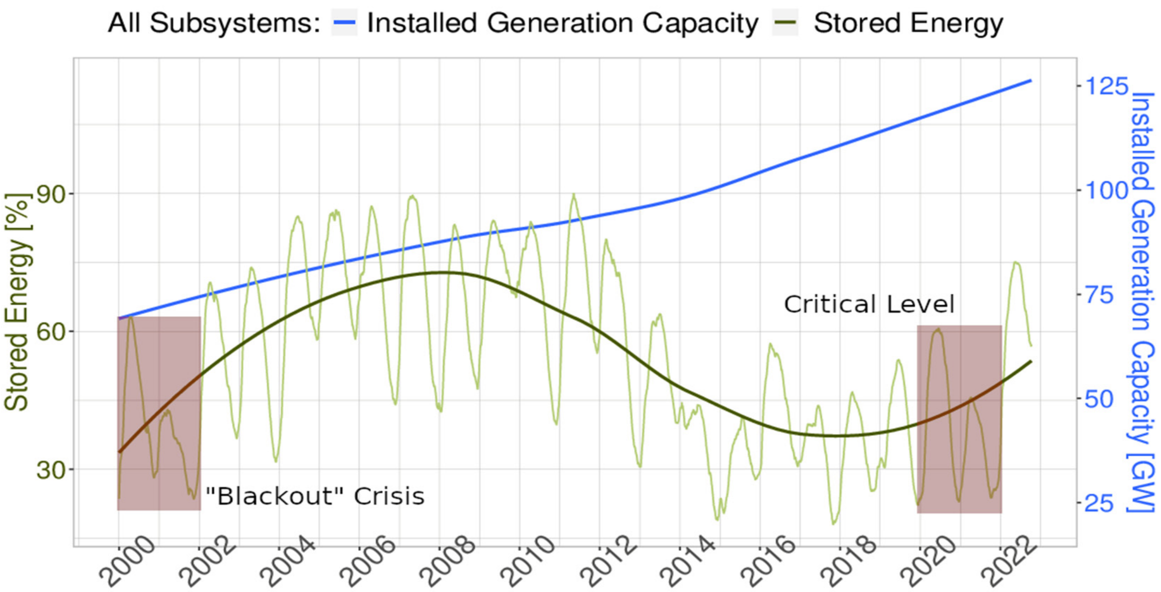

Figure 2. Stored Energy data (SED) × Installed Generation Capacity (GW)—Compiled Historical Series.

Given this situation, the need for research to understand the behavior of hydrographic basins is clear to optimize their management, rejecting the chances of new energy crisis events due to water scarcity. In these studies, the main actors to be considered are climatic factors; plant operation; the use and occupation of the area of direct influence (ADI) of the generation enterprises; the consumptive uses; geological features; and the erosive processes in the ADI, with the possibility of silting [7].

In this article, two of these factors will be analyzed: climatic factors configured by rainfall data and consumptive uses. The choice of these two variables is due to the importance of evaluating one of the main indicators of the climate for the supply of the reservoirs: the volume of rainfall and how the consumption of the actors who share the use of this system evolves. The low volume of the reservoirs is often attributed to the region's rainfall regime.

2. Materials and Methods

The Rio Grande River Basin (RGRB), located in the Southeast Region of Brazil, plays a major role in the country's water context, accounting for approximately 15.74% of hydroelectric generation in Brazil [7]. The Rio Grande, one of the main tributaries of the Paraná River, is 1286 km long and has a drainage area of 143,437.79 km^2, divided between São Paulo and Minas Gerais [8], two of the most important states in terms of economic development of the country and population [9].

In meteorological terms, along its basin, the Rio Grande has precipitation that varies between 1097 to 1812 mm/year, resulting in an average of 1423 mm/year. Eighty percent of all precipitation occurs during the rainy season, which typically starts around October and lasts until March or April. Its altitudes range from 415 to 1791 m above sea level, and the annual average temperature is 19.1 °C [10].

In order to reach the current level of electricity generation, over the years, several plants were implemented along almost the entire length of the Rio Grande (Table 1), where 4 UHEs with a generation capacity above 1000 MW stand out (Marimbondo [11], Água Vermelha [12], Furnas [13] and Luiz Carlos Barreto de Carvalho [14]).

Table 1. Hydroelectric Power Plants Implemented in Rio Grande, Brazil.

HPP	Owner	Power (MW)	Lake (km^2)	Volume (hm^3)	Type
Marimbondo [11]	Furnas	1440	438	5260	Accumulation
Água Vermelha [12]	AES Brasil	1396	647	11,000	Accumulation
Furnas [13]	Furnas	1216	1440	17,217	Accumulation
Luiz Carlos Barreto de Carvalho [14]	Furnas	1050	46	178	Run-of-river
Mascarenhas de Moraes [15]	Furnas	476	250	2500	Accumulation
Jaguara [16]	Engie	424	34	90	Run-of-river
Volta Grande [17]	Enel	380	222	2268	Run-of-river
Porto Colômbia [18]	Furnas	320	143	2335	Run-of-river
Igarapava [19]	Consórcio UHE Igarapava	210	36	234	Run-of-river
Funil [20]	Aliança Energia	180	40	258	Accumulation
Ututinga [21]	CEMIG	52	2	11	Run-of-river
Camargos [22]	CEMIG	45	73	792	Accumulation

The Furnas, Marimbondo, Luiz Carlos Barreto de Carvalho, Mascarenhas de Moraes and Porto Colombia plants comprise the list of plants (Figure 3) that were used as the object of this research. The choice of these plants is due to their relevance to the generation system of the southeast region, in addition to being managed by the same operator, Furnas (pictures and the complete technical descriptions of these hydropower plants are available on the company's official website [23]).

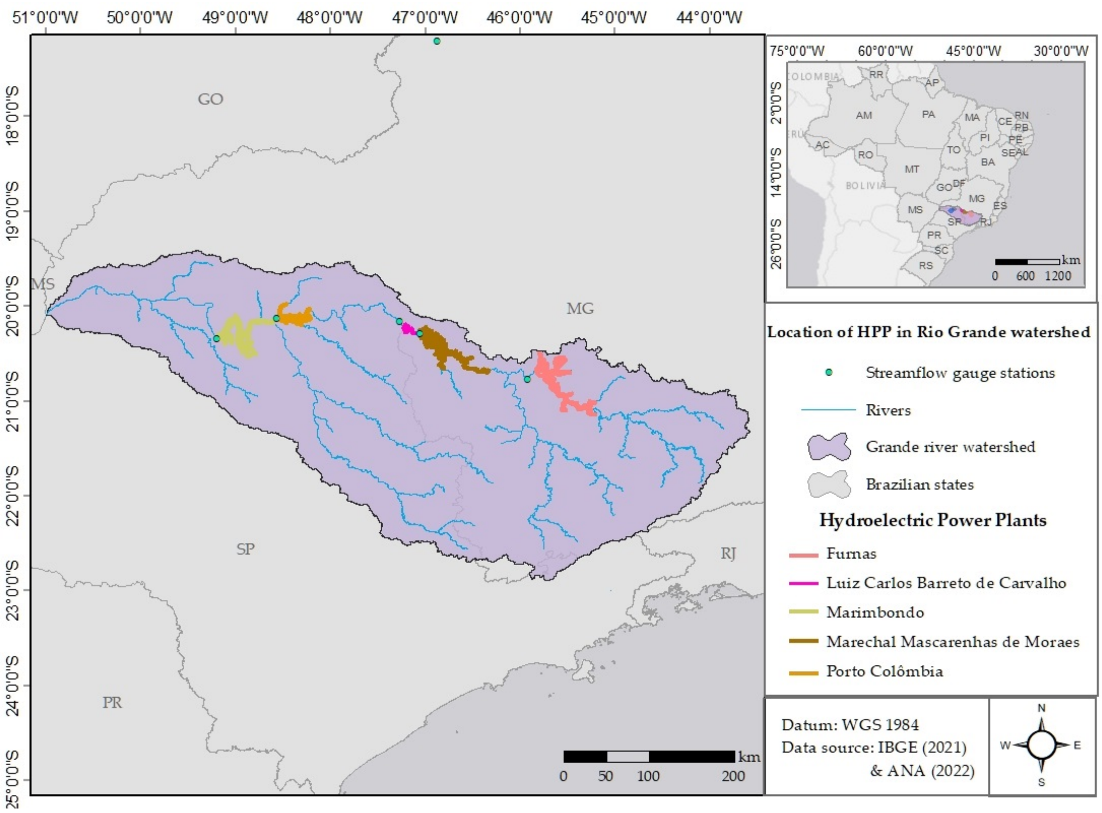

Figure 3. Location of hydroelectric plants on the Rio Grande, operated by the Furnas System.

After choosing the plants to be studied, the following section describes the methodology for the survey and statistical treatment of the variables.

2.1. Water Consumptive Uses

In order to evaluate the three main consumptive uses of water in the hydroelectric plants located on the Rio Grande, operated by the Furnas System, data were obtained from the National Agency for Water (NAW) and Basic Sanitation of the Manual of Consumptive Uses of Water (MCUW) [24], according to NAW resolution no. 92 of 2021 [25], which made the results available of the consumption and withdrawal flow calculations for each consumptive use period between 1931 and 2021. However, in this work, the series of withdrawal flows for the period between 1994 and 2021 were analyzed as this was the available range of rainfall data at the stations closest to the study area.

The upstream consumptive uses of hydroelectric plants in Brazil were calculated by NAW [25], according to the MCUW and the uses that considered the following typology: urban human supply, rural human supply, animal supply, irrigated agriculture, industrial transformation, mining and thermoelectricity. In Brazil, there is still no accurate data on land uses with an integrated reservoir management system. Even with this adversity, the present study will help to build this connection considering the total flow withdrawn and the three main uses for each hydroelectric plant located on the Rio Grande and operated by the Furnas System.

The methodology implemented by NAW [24] for calculating consumptive uses consisted of estimating technical coefficients linked to the characteristics of each use. Based on these NAW calculations, a database was obtained for each hydroelectric plant studied, with the related withdrawal flows for each consumptive use.

The calculation of the upstream flows of hydroelectric plants intended for use in urban human supply is based on the use of municipal technical coefficients extracted from the NSIS (National Sanitation Information System) databases and population counts and estimates from the Brazilian Institute of Geography and Statistics (IBGE in Portuguese).

Specifically, to obtain the withdrawal flows for urban human supply, NAW adopted minimum values for three indexes for each municipality, the urban water service index greater than 80%, the hydrometer index greater than or equal to 50% and the participation of residential savings in total water savings greater than or equal to 70%. If the municipality met these conditions, NAW calculated the per capita use, average loss and per capita withdrawal. If the municipality did not meet these conditions, NAW adopted technical coefficients by group and population.

These coefficients were related to information on the urban population obtained from IBGE population censuses (1930–2010) and IBGE annual population estimates (1992–2021).

The calculation of the flows removed related to animal supply use consisted of obtaining technical coefficients per capita (liters per day per head), by type of herd and the number of heads of agricultural census information from the IBGE (1930–1970) and IBGE Municipal Livestock Survey (1974–2021).

To calculate the flows withdrawn related to use in the manufacturing industry, NAW (2019a) obtained information from workers obtained from the IBGE industrial census (1939–2001), the IBGE industrial survey (1989–2001) and the Annual Social Information Report (RAIS in Portuguese) (2002–2021), added to obtaining withdrawal coefficients from MCUW-NAW and consumption coefficients from Ministry of Environment (MMA in Portuguese) to obtain the series of flows from 1931 to 2021 [23].

To calculate flows related to the water demand of irrigated agriculture, NAW [24] estimated the water needs of agricultural crops based on information about the climate, crops and irrigation systems. NAW [24] calculated soil water storage and effective precipitation for each crop and determined the possible deficit needed. The plant's water requirement also varied depending on the stage of development of the crop and the type of irrigation system linked to the system's efficiency due to the difference between the volume of water captured and the volume of water used by the plant.

In general, the information needed to calculate the flows were the real evapotranspiration, the effective precipitation, types and calendars of cultures in the municipalities and the types of irrigation systems and their efficiency. The final equation for calculating withdrawal flows for the use of irrigated agriculture is described below in Equation (1).

$$Q_{ret} = \sum \frac{(ET_{rc} - P_e)\ A}{E_a} \tag{1}$$

where: Q_{ret} is the flow withdrawn [m^3/s], ET_{rc} is the real evapotranspiration of the crop, P_e is the effective precipitation, A is the irrigated area, and E_a is the application efficiency of the irrigation system.

Finally, [24] indicates that the calculation of the total flow withdrawn was obtained through the sum of the withdrawal flows of the consumptive uses analyzed by NAW, referring to the uses of urban and rural human supply, animal supply, transformation industry, irrigated agriculture, mining and thermoelectricity.

Given the previous calculations carried out by NAW based on the MCUW [24] in Brazil, they were arranged in a spreadsheet available in the NAW Metadata Catalog. These data have a monthly frequency from 1931 to 2021, in Version 2.

2.2. Precipitation vs. Reservoir Level Analysis

Precipitation behavior and reservoir levels in the Rio Grande basin operated by the Furnas System were analyzed. Precipitation data were acquired from rainfall stations operated by Furnas from 1 July 1994 to 31 December 2021, as this period had the largest number of data available for the five hydroelectric plants analyzed in this study. These rainfall data are available on the Hidroweb platform of the National Water and Sanitation Agency. Table 2 presents information from the selected rainfall stations for Furnas' five hydroelectric plants on the Rio Grande.

Table 2. Details of selected rainfall stations operated by Furnas are available on the Hydroweb platform of the National Water and Sanitation Agency.

HPP	Code on NAW's Hydroweb	Station Name	Latitude	Longitude
Marimbondo	2049070	HPP Marimbondo	20°17′34.8″ S	49°11′50.2″ W
Marechal Mascarenhas de Moraes	2047045	HPP Mascarenhas de Moraes	20°17′13.9″ S	47°03′50.2″ W
Porto Colômbia	2048096	HPP Porto Colômbia	20°07′10.2″ S	48°34′24.9″ W
Furnas	2046027	HPP Furnas	20°40′33.6″ S	46°19′24.5″ W
Luiz Carlos Barreto de Carvalho	2047115	HPP Luiz Carlos Barreto de Carvalho	20°09′31.6″ S	47°16′42.2″ W

Precipitation data were acquired on a daily basis but were treated on a monthly scale to make a comparison with consumptive water use data and to facilitate the analysis of results. Table 3 describes the failure numbers in the precipitation series and is filled in with the monthly average. The Marimbondo rainfall station had the highest failures, corresponding to 5.6% of its data.

Table 3. Number of failures in the precipitation and reservoir level data series for each of the hydroelectric plants located on the Rio Grande operated by Furnas.

HPP	The Number of Failures in the Precipitation Series	The Number of Failures in the Reservoir Level Series
Marimbondo	530	2
Marechal Mascarenhas de Moraes	8	0
Porto Colômbia	13	3
Furnas	21	2
Luiz Carlos Barreto de Carvalho	30	3

The values of the levels of the Rio Grande reservoirs operated by the Furnas System were obtained for the same period of analysis of precipitation and the consumptive uses of water. The data frequency was daily, but for calculation purposes, in this article, they were transformed to a monthly frequency. Missing data from the data series on reservoir levels and precipitation were filled in with the monthly average.

2.3. Statistical Analyses

To facilitate the subsequent data series analysis, general statistics such as the mean, the coefficient of variation and the minimum and maximum values were calculated. Moreover, to analyze the temporal trend of the data, the Mann–Kendall test was applied using the free software Past3.

The Mann–Kendall trend test [26,27] consists of a non-parametric test with zero sensitivity to atypical data, and the data distribution need not be normal [28]. This test is widely used in the hydrological and climatic analysis [29].

The parameters calculated in the Mann–Kendall trend test are the sign (S), the statistical value of the standardized test (Z) and the p-value determined by the significance level, $\alpha = 0.05$. The theoretical foundation of the test was explained by Ashraf et al. [30], and the equations of this test are detailed below.

The sign calculation (S) is based on Equation (2), where positive values of S indicate an increasing trend and negative values of S indicate a decreasing trend.

$$S = \sum_{k=1}^{n-1} \sum_{j=k+1}^{n} sinal\left(S_j - S_k\right) \tag{2}$$

$$sinal\left(S_j - S_k\right) = \begin{cases} se\ f\left(S_j - S_k\right) < 0 & ;\ n \quad -1 \\ se\ f\left(S_j - S_k\right) = 0 & ;\ n \quad 0 \\ se\ f\left(S_j - S_k\right) > 0 & ;\ n \quad 1 \end{cases}$$

where Y_k and Y_j are consecutive time series values over time and n is the amount of data.

The standardized test statistical value (Z) is calculated using Equation (3) and is useful in verifying the null hypothesis.

$$Z = \begin{cases} \frac{S-1}{\sqrt{VAR(S)}}, & se \quad S > 0 \\ 0, & se \quad S = 0 \\ \frac{S+1}{\sqrt{VAR(S)}}, & se \quad S < 0 \end{cases} \tag{3}$$

VAR(S) is the variance of the signal value, S.

In this study, the null and alternative hypotheses were defined as follows:

- Null hypothesis (H_o): The time series of water consumptive use, precipitation and reservoir levels do not show an increasing or decreasing trend over time.
- Alternative hypothesis (H_a): The time series of water consumptive use, precipitation and reservoir levels show an increasing or decreasing trend over time.

3. Results and Discussion

3.1. Consumptive Use

According to Table 4, the three main uses were for urban human supply for the hydroelectric plants of Furnas, Marechal Mascarenhas de Moraes and Luiz Carlos Barreto de Carvalho, animal use and irrigated agriculture. While the two remaining hydroelectric plants, Marimbondo and Porto Colombia, the three main uses were for urban human supply, the processing industry and irrigated agriculture.

The graphs of the withdrawal flow for the main uses and the total flow withdrawn for the plants in the Rio Grande, under Furnas operation, are presented in Figures 4 and 5, separated into run-of-river projects and accumulation. Run-of-river projects are those that have reservoirs with reduced dimensions, with only a small flooded area, and the accumulation projects are characterized by promoting the greater accumulation of water. Consequently, energy upstream of the dam provides a more constant generation. Additionally, Figures 4 and 5 indicate, respectively, a growth rate in the last 10 years of 21.0% and 18.7%.

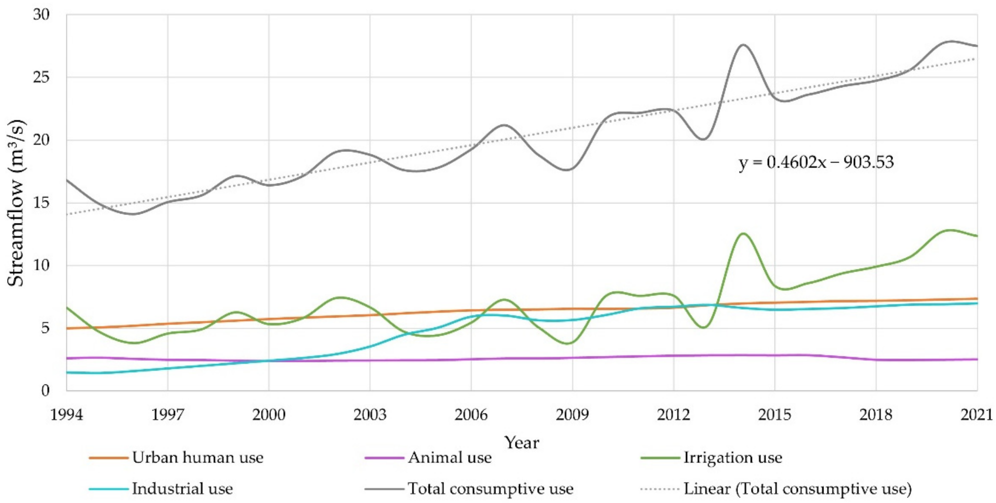

Figure 4. Average water use in hydroelectric plants Luiz Carlos Barreto de Carvalho and Porto Colombia (run-of-river).

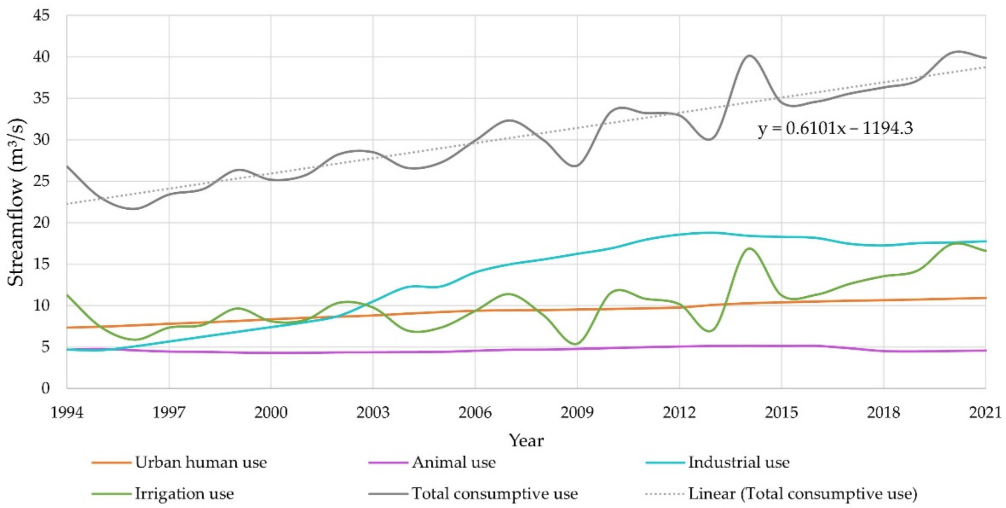

Figure 5. Average water use at Marechal Mascarenhas de Moraes, Furnas and Marimbondo hydroelectric plants (accumulation).

The hydroelectric plant with the highest average in consumptive uses of water was the Marimbondo plant, and the lowest average was the Furnas plant (Table 4). It was also observed that the highest values on average were for human supply in urban areas, followed by water intended for irrigation. The coefficients of variation (CV) of consumptive uses, comparing the plants to each other, have the same pattern. This fact is due to the proportionality methodology used by NAW in its manual [23]. The highlighted value of CV for irrigation, with an average value among the plants of 83%, indicates the clear growth of this use compared to the others.

Table 4. General statistics on water uses in the reservoirs of Furnas, Luiz Carlos Barreto de Carvalho, Marechal Mascarenhas de Moraes, Marimbondo and Porto Colombia.

HHP	Use	Mean (m^3 s^{-1})	Coefficient of Variation (%)	Minimum (m^3 s^{-1})	Maximum (m^3 s^{-1})
Furnas	Urban human	4.39	10.82	3.44	5.08
	Animal	2.14	5.75	1.97	2.36
	Irrigation	4.75	82.87	0.00	18.73
	Total consumptive	13.15	31.48	7.28	27.92
Luiz Carlos Barreto de Carvalho	Urban human	5.10	10.73	4.00	5.88
	Animal	2.58	5.97	2.38	2.86
	Irrigation	5.39	84.23	0.00	21.89
	Total consumptive	15.37	31.30	8.53	32.72
Marechal Mascarenhas de Moraes	Urban human	4.95	10.71	3.88	5.71
	Animal	2.52	6.11	2.32	2.80
	Irrigation	5.29	84.18	0.00	21.47
	Total consumptive	14.96	31.50	8.32	31.97
Marimbondo	Urban human	18.73	11.59	14.65	22.12
	Industry	13.30	37.90	4.55	18.88
	Irrigation	20.87	83.93	0.00	61.94
	Total consumptive	63.62	31.84	30.95	109.00
Porto Colômbia	Urban human	7.63	10.96	5.93	8.86
	Industry	4.87	41.71	1.39	7.02
	Irrigation	8.86	83.42	0.00	30.60
	Total consumptive	25.34	34.17	11.81	50.01

3.2. Precipitation and Reservoir Levels

The graphs showing the precipitation and reservoir level for the plants on the Rio Grande under Furnas operation are presented in Figures 6 and 7, separated into run-of-river projects and accumulation projects. It can be observed that the precipitation has a regular behavior over the years analyzed as the level of the reservoirs fluctuates seasonally. This aspect demonstrates the reduced dependence between the precipitation factor and reservoir level in the adopted scale.

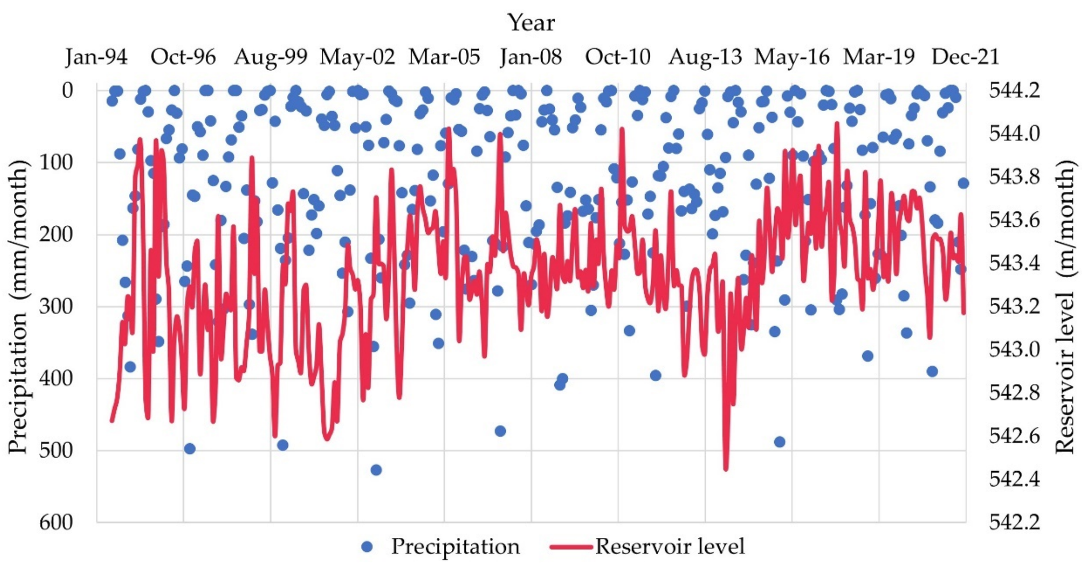

Figure 6. Average precipitation and reservoir levels at the Luiz Carlos Barreto de Carvalho and Porto Colombia HPPs (run-of-river).

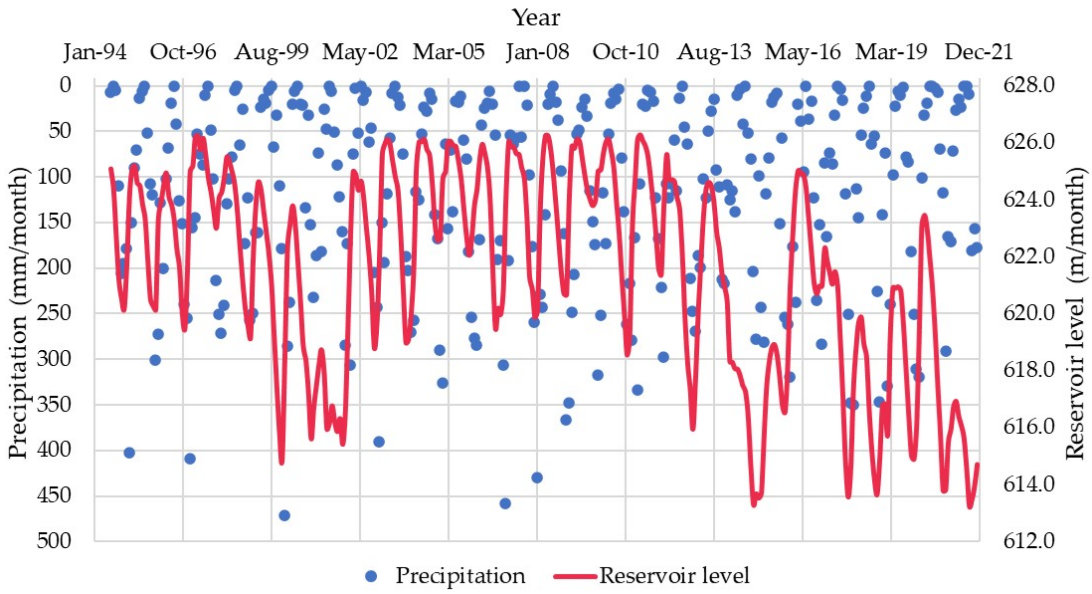

Figure 7. Average precipitation and reservoir levels at the Marechal Mascarenhas de Moraes, Furnas and Marimbondo HPPs (accumulation).

The results of the general statistics, the average, CV and the minimum and maximum values, on the levels of the reservoirs and precipitation, for each hydroelectric plant located in the Rio Grande, operated by the Furnas system, are presented respectively in Tables 5 and 6.

Table 5. General statistics of the levels of the reservoirs of Furnas, Luiz Carlos Barreto de Carvalho, Marechal Mascarenhas de Moraes, Marimbondo and Porto Colombia.

HHP	Mean (m/Month)	Coefficient of Variation (%)	Minimum (m/Month)	Maximum (m/Month)
Furnas	762.07	0.60	752.37	767.90
Luiz Carlos Barreto de Carvalho	620.32	0.08	618.81	621.45
Marechal Mascarenhas de Moraes	663.25	0.43	655.21	665.99
Marimbondo	439.07	1.14	428.09	445.45
Porto Colômbia	466.36	0.05	465.80	467.00

Table 6. General precipitation statistics from Furnas, Luiz Carlos Barreto de Carvalho, Marechal Mascarenhas de Moraes, Marimbondo and Porto Colombia.

HHP	Mean (mm/Month)	Coefficient of Variation (%)	Minimum (mm/Month)	Maximum (mm/Month)
Furnas	110.06	95.35	0.00	545.30
Luiz Carlos Barreto de Carvalho	123.35	96.03	0.00	588.20
Marechal Mascarenhas de Moraes	131.68	93.14	0.00	654.10
Marimbondo	113.45	96.83	0.00	512.50
Porto Colômbia	119.26	99.71	0.00	643.90

Regarding the reservoir level, the plant with the highest coefficient of variation is the Marimbondo plant, followed by the Furnas plant, both accumulation plants. As for precipitation, a certain uniformity can be observed between the telemetric stations found in each plant as the amplitude of the CV is of the order of 3%, and the Mascarenhas de

Moraes plant has the highest average precipitation (131.68 mm/month) and the highest maximum value (654.10 mm/month).

3.3. Trend Test

The results of the Mann–Kendall trend test for the hydroelectric plants analyzed are presented in Table 7, pointing to the trends in the variables: precipitation, reservoir level and consumptive uses.

Table 7. Mann–Kendall trend test.

HHP	Data	S	Z	*p* (No Trend)	Trend
Furnas (accumulation)	Precipitation	−1381	0.69	0.49	No trend
	Reservoir level	−12,547	6.26	3.74×10^{-10}	Decreasing
	Urban human use	53,674	26.80	0.00	Increasing
	Animal watering use	20,865	10.42	0.00	Increasing
	Irrigation use	8166	4.08	4.56×10^{-5}	Increasing
	Total consumptive use	14,965	7.47	0.00	Increasing
Luiz Carlos Barreto de Carvalho (run-of-river)	Precipitation	−1302	0.65	0.52	No trend
	Reservoir level	13,252	6.62	0.00	Increasing
	Urban human use	53,662	26.79	0.00	Increasing
	Animal use	17,981	8.98	0.00	Increasing
	Irrigation use	9504	4.75	2.09×10^{-6}	Increasing
	Total consumptive use	16,461	8.22	0.00	Increasing
Marimbondo (accumulation)	Precipitation	221	0.11	0.91	No trend
	Reservoir level	−6902	3.45	5.69×10^{-4}	Decreasing
	Urban human use	54,285	27.11	0.00	Increasing
	Industry use	41,685	20.81	0.00	Increasing
	Irrigation use	9375	4.68	2.86×10^{-6}	Increasing
	Total consumptive use	21,317	10.64	0.00	Increasing
Marechal Mascarenhas de Moraes (accumulation)	Precipitation	−867	0.43	0.67	No trend
	Reservoir level	−24,343	12.16	0.00	Decreasing
	Urban human use	53,700	26.80	0.00	Increasing
	Industry use	19,047	9.51	0.00	Increasing
	Irrigation use	9416	4.70	2.59×10^{-6}	Increasing
	Total consumptive use	16,231	8.10	0.00	Increasing
Porto Colômbia (run-of-river)	Precipitation	−1305	0.65	0.51	No trend
	Reservoir level	9559	4.77	1.81×10^{-6}	Increasing
	Urban human use	53,799	26.86	0.00	Increasing
	Industry use	47,644	23.79	0.00	Increasing
	Irrigation use	12,225	6.10	1.04×10^{-9}	Increasing
	Total consumptive use	23,766	11.87	0.00	Increasing

According to the Mann–Kendall trend test, the three main water uses had a statistically significant increasing trend over time in all hydropower plants analyzed. Precipitation showed no trend, while reservoir levels showed a downward trend for all accumulation plants and a growing trend for all run-of-river plants. This aspect demonstrates greater fragility, exposure to seasonality, and consumptive uses for plants with accumulation-type reservoirs.

4. Conclusions

Fluctuations in reservoir levels directly impact the SED, therefore it has certain repercussions on the country's energy security. Usually, the media only attributes the effects of climate change and pays little attention to integrated land uses [31–33]. Understanding all factors influencing these values is essential for balanced and sustainable management in this sector.

Analyzing the five plants located on the Rio Grande and operated by Furnas, the following was observed, using conventional statistical indicators: CV, average, maximum and minimum and the Mann–Kendall trend test, the behavior of the reservoirs and the connection with precipitation and consumptive uses, based on the historical series from 1994 to 2021 (27 years).

Surely, there are uncertainties regarding rainfall and loading to the reservoir. By now, we have presented rain data, but we still need to evaluate the hydrogeological issue that influences stored water results. Anyway, the importance of this cycle in the reservoir filling process is undoubted, although we did not have data in hand to analyze it at this time.

From the data analyzed in this article, it was identified that the precipitation factor is not the most relevant factor due to the water crisis in these projects. There is a certain consistency in the behavior of the level of the reservoirs with the competing consumptive use as one increases and the other decreases in a clear time trend. The fact is that this behavior cannot be attributed exclusively to consumptive uses since the operation, infiltration rates (depending on land cover and use), and geology, among other variables, are also known to have important repercussions on the behavior of reservoirs.

Conclusively, the recovery capacity, especially of the accumulation reservoirs is increasingly compromised, and the consumptive use demands more and more water resources for its maintenance, mainly to supply agribusiness through irrigation. Undoubtedly, policies that balance the energy interest with other demands must be discussed and systematized with public policies so that situations of water and energy rationing do not become a routine in Brazil. Contingency plans should be used to mitigate the problem, as they usually focus on restricted sectors and sustain the solution for a determined period. Long-term solutions demand greater synergy between the industries that depend on this essential natural resource.

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