Revista AIDIS de Ingeniería y Ciencias Ambientales:
Investigación, desarrollo y práctica. ISSN 0718-378X

http://dx.doi.org/10.22201/iingen.0718378xe.2022.15.3.81530
Vol. 15, No.3, 1421-1446
6 de diciembre de 2022

REVISTA AIDIS

de Ingeniería y Ciencias Ambientales:
Investigación, desarrollo y práctica.

WATER SCARCITY AND RAW WATER CHARGES IN THE STATE OF CEARÁ, BRAZIL

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Recibido el 5 de enero de 2022. Aceptado el 25 de marzo de 2022

Abstract
Economic instruments, such as water charges, have been used to promote water conservation and raise funds for basin management. However, there is a need to improve the water collection model in Brazil. The aims of this study were to analyze the evolution of raw water charges in the State of Ceará and verify the effect of drought on the costs and water collection from 2011 to 2019 to answer two questions: does the water collection fulfill its function of financing the water resources system? Is the pricing model flexible to absorb the effects of climate variability? We conducted a content analysis to determine the presence of certain words in selected documents, and then analyzed the costs of system operation. The results show that the payment capacity is lower than the tariff applied to water. The Status Index is negatively correlated with the Administration (ADM) and Operation and Maintenance (O&M) costs. The generated revenue is mainly used to cover the management costs (ADM and O&M); however, it is insufficient to finance the implementation of measures, programs, and projects to improve the water management in respective basins. Thus, a floating tariff should be established in which the water scarcity and effects of climate variability are incorporated.

Keywords: economic instrument, management water cost, water resources management, water collection.

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Introduccion

Climate variability is associated with the risks of hydrological extremes, especially in regions with frequent drought events in which low-frequency variability is relevant (Rocha *et al*., 2019). Changes in temperature and precipitation patterns are indirectly connected to resource access, which can lead to scarcity with respect to multiple and competing demands, intensifying conflicts linked to political, economic, and social factors (Froese & Schilling, 2019). Managing these risks requires flexibility and the ability of legal and institutional systems to have autonomy in decision-making related to structural and non-structural actions of water systems related to extreme events and changes in society and economy. Thus, water resources management must reconcile with risk management to achieve successful studies, plans, and programs.

For this purpose, regulatory and economic instruments are used. Their aims are to align the individual's behavior with the objectives of public policies to provide water in quantity and quality to the population and mitigate the risks related to the supply (Rey *et al*., 2019).

Berbel *et al.* (2019) reported that the ideal mix of water policies should include both the supply and demand and economic and non-economic instruments should be linked to conventional command and control policies.

Based on Dalcin & Fernandes Marques (2020), the implementation and coordination of these instruments to meet current and future goals are limited depending on the region or country. Thus, detailed analyses of the physical, economic, and legal conditions are required.

In Brazil, the base of water resources management is the integrated, participatory, and decentralized management by the State, civil society, and users (Libanio, 2018). The Water Law (Law No. 9,433/1997) includes the following management instruments (Brasil, 1997): water resource plans; classification of waterbodies based on the predominant water use; granting of rights to use water resources; charging for the use of raw water; and water resource information system. The instruments should be applied to the territorial unit, that is, the hydrographic basin, to obtain a systemic view of a given territory's water resources including environmental, social, and economic aspects (ANA, 2020).

Based on a study of Porto & Porto (2008), the Water Law is flexible and can be adapted to the hydrographic basins and their social, political, economic, and climatic conditions. Based on the law, it is not mandatory to adopt all instruments in the basins and others instruments can be added depending on the basins' needs.

One of these instruments, which has attracted attention in the last two decades, is charging for raw water. It is a public price because the revenue directly originates from the exploitation of a public good and is gradually applied in federal and state basins (ANA, 2014; Ferreira *et al*., 2020).

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The economic function of this instrument is to encourage water conservation through the price and its financial function is a fundraising mechanism to finance the water resources system (Cerqueira, 2019). The tariff structure relies on sending a message to consumers such that the tariff price allows cost recovery and supports political, economic, social, and environmental policies (Pinto et al., 2021).

De Sousa & Dias Fouto (2019) demonstrated that these economic incentives effectively reduced the water consumption in São Paulo during the water crisis. Lopez-Nicolas *et al.* (2018) came to the same conclusion and reported that water pricing policies still have a significant untapped potential, especially in cases of water scarcity.

De Brito & De Azevedo (2020) reported that the implementation of raw water charges was a success. However, based on the comparison of the Brazilian charge model with that of countries such as France, Australia, and Canada, this instrument must be improved, mainly with respect to the water collection model. The Organization for Economic Cooperation and Development (OECD) emphasized three aspects: universal water charge because not all states have implemented it; higher charge for those who use more; and decision upon how much to charge.

This raises several questions: is the raw water charge sufficient to cover the costs of the system operation? In other words, did the raw water charge fulfill its function of financing the water resources system? Is the pricing model flexible to absorb the effects of climate variability?

We used content analysis to analyze the evolution of raw water charges in the State of Ceará, focusing on federal and state laws and resolutions of the State Council for Water Resources (*CONERH*). We also verified the systems' operating costs, water collection, and correlation with drought from 2011 to 2019.

We used the State of Ceará as study area, which has a history of droughts. Thus, the results of this study can be used as guidance in other regions that suffer from climatic variability and will help to improve or establish the collection of fees for raw water use.

Study Area

The State of Ceará is in the northeastern part of Brazil and covers an area of 148,894.4 km² (IBGE, 2020). More than 90% of the territory is in the semi-arid region, characterized by low precipitation and high evaporation rates. Therefore, this region is vulnerable to droughts (Pontes Filho *et al,* 2020).

The main rainy season occurs from February to May and rain represents the meteoric water used in rainfed agriculture and rural cisterns. However, owing to the oceanic and atmospheric conditions, rainfall is characterized by a significant spatiotemporal variability and is often insufficient to meet the demand of reservoirs.

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The 155 state reservoirs are considered to be strategic with respect to the storage and transport of water from rainy years to subsequent dry years and are characterized as multi-annual. Therefore, they are responsible for reducing the state's seasonal and interannual variability. Table 1 shows the number of reservoirs in each hydrographic basin in Ceará. The Middle Jaguaribe Basin has the largest storage capacity, whereas the Upper Jaguaribe Basin has the largest number of reservoirs.

Table 1. Storage capacities of hydrographic basins.

Hydrographic basin	Number of reservoirs	Storage capacity (hm³)
Acaraú	15	1,719.42
Upper Jaguaribe	24	2,765.67
Lower Jaguaribe	1	24.00
Banabuiú	19	2,687.84
Coreaú	10	301.68
Curu	13	1,028.80
Litoral	10	214.90
Middle Jaguaribe	15	7,373.99
Metropolitana	22	1,383.78
Salgado	15	447.45
Serra da Ibiapaba	1	140.33
Sertões de Crateús	10	436.04
Total	155	18,523.90

Source: Ceará Meteorology and Water Resources Foundation - Funceme (2022).

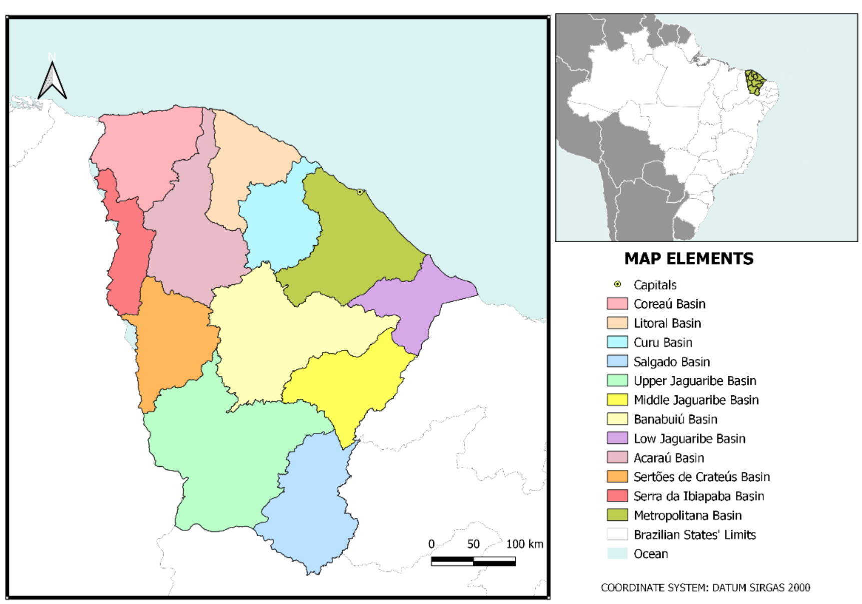

Figure 1. Hydrographic basins in the State of Ceará.

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The State of Ceará is spatially divided into 12 hydrographic basins to effectuate the management of water resources: Metropolitana, Curu, Litoral, Acaraú, Coreaú, Serra da Ibiapaba, Sertões de Crateús, Banabuiú, Salgado, and the Upper, Middle, and Lower Jaguaribe (Figure 1). Thus, we focused on regional administrations in this study. Several hydrographic basins were merged to facilitate their management.

Materials and methods

In this study, the evolution of raw water charges was analyzed, and a cost analysis was carried out for the operating system in Ceará from 2011 to 2019. We divided the methodology into two parts: content analysis and total cost analysis. We applied the Status Index (SI) to verify the correlation between the dry state of hydrographic basins and the variation in costs.

Content analysis

Content analysis is used to analyze written, verbal, or visual messages. It emerged in the early 20th century in the United States to analyze journalistic materials. Later, scientists applied this technique to political speeches (Bardin, 2010; Schiavini & Garrido, 2018). Currently, it is widely applied in several fields.

We applied this method to observe changes in the raw water charges over the years. These changes involve adjustments in tariff amounts, usage categories, and charging criteria. The application of this method can be divided into three phases, as described by Bardin (2010): (i) Pre-analysis: material organization; (ii) Material exploration: The data are classified and categorized; and (iii) Results and interpretation. In this method, the emphasis is placed on counting the occurrences of words, phrases, or themes. Therefore, we searched for the words "Charge" and "Tariff" in the study materials and subsequently read the selected documents and assembled a timeline.

Our study material included the resolutions of *CONERH*, which are available on the website of the Water Resources Secretariat (*SRH*), and the State Laws 11,996/92 and 14,844/2010, which are provided by the State Water Resources Policy and instituted the Integrated Water Resources Management System (*SIGERH)*.

After the content analysis, we compared the tariff values with the "Payment Capacity" because an ad hoc tariff model referring to the "Payment Capacity" and "Cross-Subsidy" (Equations 1, 2, and 3) was used to determine tariff increases. The payment capacity refers to the maximum rate that can be applied to each user sector. The equation is based on each class of a user's gross income for the last year of available statistics updated by the General Price Index - Internal Availability (IGP-DI) index provided by the Getúlio Vargas Foundation. We applied the cross-subsidy to exemption, subsidy, average tariff, or surcharge categories of consumption.

$$M = \sum_{w=1}^{n} (Ts_i \, . \, \forall_i) \qquad \textbf{Equation (1)}$$

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where M is the water collection with the raw water use charge of the i-th class of users (R$/yr); Ts_i is the unit tariff of the i-th class of users (R$/m³); ∀ is the volume of water consumed by the i-th class of users (m^3/month); and w is the number of months.

$$Ts = (1 + S) * Tm \qquad \textbf{Equation (2)}$$

where S is the cross-subsidy factor and Tm is the average user sector tariff (R$/m³).

$$Tm = \theta \cdot UPC \qquad \textbf{Equation (3)}$$

where θ is the parameter that defines the fraction of the payment capacity to be charged (0 < θ <1), which is manually calibrated, and UPC is the sector's unit payment capacity (R$/m³).

$$S = \frac{\propto}{1+e^{-\beta (Qr)^2}} - \gamma,$$

where $\propto, \beta \; and \; \gamma$ are parameters and Qr is the reference flow of the class of users of an industry. The unit of measurement of Qr can be disregarded.

The conditions for the cross-subsidy are as follows: If S = –1, Ts = 0. If –1 < S < 0, the tariff is subsidized for user class i. If S = 0, the average tariff is applied. If S > 0, the overcharge is applied.

Analysis of the system management cost

We obtained the management costs of the water resources system from 2011 to 2019 from the Water Resources Management Company *(COGERH)*. We divided them into Administration costs (ADM) and Operating and Maintenance costs (O&M) for the analysis of the expenses.

Administration costs refer to salaries, labor charges, transportation, tax obligations, and indemnities. The O&M costs refer to the conservation, monitoring, and operationalization of the water infrastructure and electricity.

We calculated the unit cost (R$/m³) by determining the ratio of the total costs and consumption billed by each regional administration. Based on the unit cost, the evolution of the price of water can be visualized in a simplified way.

We applied Pearson's correlation to analyze the relationship between the costs and hydrological drought. Pearson's correlation coefficient (Equation 4) indicates the variable strength of a correlation and can vary from +1 to -1. A value closer to 1 reflects a positive linear correlation, whereas a value closer to -1 represents a negative linear correlation. When the correlation coefficient is zero, there is no correlation (Nunes Carvalho *et al*., 2021). We used the Corrplot package of software R to obtain the correlation.

$$r_{xy} = \frac{\sum_{i=1}^{n}(x_i-\bar{x})(y_i-\bar{y})}{\sqrt{\sum_{i=1}^{n}(x_i-\bar{x})^2}\sqrt{\sum_{i=1}^{n}(y_i-\bar{y})^2}}, \qquad \textbf{Equation (4)}$$

where x and y are variables.

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$$If\ V_i \geq V_{med} \quad \rightarrow\ I_e = \frac{1}{2}\left[1 + \frac{V_i - V_{med}}{V_{max} - V_{med}}\right] or\ V_i < V_{med} \quad \rightarrow\ I_e = \frac{V_i - V_{min}}{2(V_{med} - V_{min})}, \qquad \textbf{Equation (5)}$$

where V_i is the volume measured in the analyzed period, V_{med} is the average volume of the historical period, V_{max} is the maximum volume of the historical period, and V_{min} is the minimum volume of the historical period.

The SI characterizes the hydrological drought. This index is dimensionless and has values ranging between 0 and 1, which correspond to the minimum and maximum historical value (Araújo Junior *et al.,* 2020), respectively. The SI calculation is shown in Equation 5 and its categorization is listed in Table 2.

Table 2. Categories of the Status Index.

Status	SI
Regular	SI > 0.5
Pre-Alert	0.5 ≥ SI > 0.3
Alert	0.3 ≥ SI > 0.15
Emergency	0.15 ≥ SI

Source: Araújo Junior et al. (2020).

We added the volumes of each basin's reservoirs, creating a reservoir equivalent to the SI calculation. The volumes refer to December of each year to avoid false information about the rainy season. We compared the costs with the annual raw water collection to verify the financial sustainability of the water resources system. We obtained the water collection data from the website of the National Water Agency (ANA).

Results

Evolution of raw water charges

The raw water charges are applied to users who consume raw underground or surface water and who hold the grant of use. The following user categories are considered: Public supply, Industry, Fish farming, Shrimp farming, Spring and drinking water, Irrigation, Service and Business, and Other categories of use. Table 3 presents the consumption percentages of each category, except for Service and Business and Other categories of use for which not enough information is available.

Human supply is the category that consumes the most water, followed by irrigation. As of 2013, a decrease in the irrigation consumption can be observed over the years, which is due to drought and the increased consumption for human supply. Charges are not incurred for insignificant water use, such as the water used to satisfy the needs of small population centers distributed in rural areas, and derivations, accumulations, and borrowings considered to be insignificant and/or in a state of public calamity. The main events related to the expansion and/or improvement of this management instrument in Ceará are shown in Figure 2 and Table 4.

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Table 3. Categories and consumed volume.

Year	Categories	Consumed Volume (m³)	Percentage of Consumed Volume
2011	Human supply	418,519,793.02	77.07%
	Industry	10,244,935.82	1.89%
	Irrigation	96,276,903.90	17.73%
	Fish farming	3,215,248.88	0.59%
	Shrimp farming	14,662,763.40	2.70%
	Spring and drinking water	137,297.41	0.03%
2012	Human supply	448,922,743.72	65.81%
	Industry	20,304,671.57	2.98%
	Irrigation	185,955,772.82	27.26%
	Fish farming	4,074,500.02	0.60%
	Shrimp farming	22,870,845.01	3.35%
	Spring and drinking water	44,069.96	0.01%
2013	Human supply	451,928,753.13	53.52%
	Industry	30,677,449.08	3.63%
	Irrigation	311,850,048.41	36.93%
	Fish farming	3,943,285.76	0.47%
	Shrimp farming	45,348,475.40	5.37%
	Spring and drinking water	690,982.04	0.08%
2014	Human supply	499,551,341.00	55.04%
	Industry	38,007,813.07	4.19%
	Irrigation	308,013,616.96	33.93%
	Fish farming	7,703,343.43	0.85%
	Shrimp farming	53,841,249.39	5.93%
	Spring and drinking water	578,352.95	0.06%
2015	Human supply	498,599,038.41	62.07%
	Industry	33,604,298.06	4.18%
	Irrigation	217,823,115.25	27.12%
	Fish farming	3,726,888.03	0.46%
	Shrimp farming	49,238,098.45	6.13%
	Spring and drinking water	318,399.01	0.04%
2016	Human supply	440,690,299.81	70.24%
	Industry	36,542,266.45	5.82%
	Irrigation	126,703,319.86	20.19%
	Fish farming	2,104,051.75	0.34%
	Shrimp farming	20,868,662.87	3.33%
	Spring and drinking water	518,439.03	0.08%
2017	Human supply	444,268,906.46	76.14%
	Industry	38,965,328.79	6.68%
	Irrigation	93,929,510.95	16.10%
	Fish farming	1,209,177.71	0.21%
	Shrimp farming	4,461,071.53	0.76%
	Spring and drinking water	623,003.82	0.11%
2018	Human supply	460,440,034.87	77.12%
	Industry	39,555,501.10	6.62%
	Irrigation	83,555,232.86	13.99%
	Fish farming	775,119.09	0.13%
	Shrimp farming	12,133,862.21	2.03%
	Spring and drinking water	609,517.88	0.10%
2019	Human supply	472,380,403.17	77.24%
	Industry	37,971,395.48	6.21%
	Irrigation	95,522,810.26	15.62%
	Fish farming	485,215.36	0.08%
	Shrimp farming	4,578,216.20	0.75%
	Spring and drinking water	608,879.93	0.10%

Source: Secretaria Dos Recursos Hídricos (2016) and COGERH (2020). Information provided by COGERH via the Transparency Portal on November 10, 2020.

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Table 4. Raw water collection timeline.

Year	Norm/Law/Resolution	Origin	Explanation	Tariff change by raw water charges
1992	n° 11996	State	Ceará State's water management began with the State Water Resources Law. This law established the State Water Resource Policy and Integrated Water Resources Management System (**SIGERH**). It designates institutions for this management and establishes that the primary management unit is the hydrographic basin. With respect to water collection, this law describes that the use of surface or underground water resources will be charged according to the peculiarities of the hydrographic basins considering the classification of waterbodies in classes based on the predominant water use, local water availability, regularization ensured by hydraulic works, flow and its variation regime, effective consumption, and intended purpose. With respect to the dilution, transportation, and assimilation of sewage system effluents and other liquids of any nature, the class of use in which the receiving waterbody is included, regularization ensured by hydraulic works, load released and its variation regime, organic and physicochemical parameters of the effluents, and nature of the activity responsible for them will be considered.	
1993	Law n° 12217	State	The management started after the creation of COGERH. The purpose of this institution is to manage the supply of surface and underground water resources in the state's domain.	
1996	Ordinance n°24264	State	Raw Water Charge Implementation. Ceará State was one of the federation units that anticipated the Union to enact a specific law for water resources. The State Water Resources Council (CONERH) empowered COGERH to manage all reservoirs in the State of Ceará as well as to charge for the use of raw water to be reimbursed for the services under their responsibility. Three categories of water users were established: industries; potable water service concessionaires; and users to which the water is delivered pressurized, pumped, or channeled. However, values were allocated only to the first two categories, that is, R$12.17/ 1000 m³ and R$730.00/1000 m³, respectively.	
1997	Law n°9433	Federal	Creation of the Nacional Water Resource Policy. Water is defined as a public good and endowed with an economic value that must satisfy its multiple uses, with human use and animal feed as priorities. It establishes charging as an instrument of the National Water Resources Policy and settles parameters similar to those in State Law No. 11,996/92 such as water derivations, abstractions and extractions, the volume removed and its variation regime, and sewage releases with variation in the tributary's physicochemical, biological, and toxicity characteristics. However, it foresees the use of the amounts collected to finance studies, programs, projects and the establishment of the limit of seven and a half percent of the total collected to be applied to administrative costs of the institutions that are part of the National Water Resource Management System. In addition, each state/hydrographic basin is responsible for its methodology and application.	
2003	Resolution n°02	State	New tariffs and new categories of users are considered: Fish farming, Shrimp farming, Spring and drinking water and irrigation. Note that irrigation prices vary according to the consumption and the supply in the Metropolitan Region of Fortaleza (MRF) and inland regions differs. This resolution also mentions the binomial form of water collection, which involves a component related to consumption (consumption tariff) and another equivalent to the demand granted (demand tariff). However, due to the need to structure the management institutions, universalization of the grant, greater understanding, and acceptance by users, the monomial charging type was implemented according to the consumed volume. This model is still used.	I – Human Supply: a) MRF: R$55,00/1.000 m³; b) Inland: R$26,00/1.000 m³; II - Industry: R$803,60/1.000 m³; III – Fish farming: a) in excavated tanks: R$13,00/1.000 m³; b) in net tanks: R$26,00/1.000 m³; IV – Shrimp farming: R$26,00/1.000 m3; V – Spring and drinking water: R$803,60/1.000 m³; VI – Irrigation: a) 1441 m³/month up to 5.999 m³/ month consumption: R$2,50/1.000 m³; b) 6.000 m³/month up to 11.999 m³/ month consumption: R$5,60/1.000 m³; c) 12.000 m³/month up to 18.999 m³/ month consumption: R$6,50/1.000 m³; d)19.000 m³/month up to 46.999 m³/ month consumption: R$7,00/1.000 m³; e) consumption above 47.000 m³/month: R$8,00/1.000 m³; VII – Other uses: R$55,00/1000 m³.

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Year	Norm/Law/Resolution	Origin	Explanation	Tariff change by raw water charges
2006	Resolution n°02	State	Tariff change.	This increase varied between 20% and 29%, with the smallest increases in Pisciculture, Shrimp, and Irrigation and the largest ones in Industry and Spring and drinking water.
2010	Law n°14844	State	It replaced the law 11996/92.	
2010	Resolution n°03	State	Created a subitem for the Public supply category to include cases in which the supply of raw water is implemented by COGERH through pressurized piping for pumping.	
2011	Resolution n°01	State	The supply of raw water by capture and adduction through pressurized piping for pumping was added to the Others category. The tariff values also changed.	Public supply and industry showed a variation of 43%. Due to the new division of categories in With and Without Adduction, the values without adduction were reduced such as in Pisciculture, Shrimp, and Irrigation.
2012	Resolutions n°04 and 05	State	Tariff change.	Increases were of the order of 6% and some categories such as Irrigation, Fish farming in tanks excavated with adduction, and Shrimp farming with adduction did not change
2013	Resolution n°05	State	Tariff change.	The tariff increased by 4% in all categories.
2015	Resolution n°02	State	Tariff change.	Increase of 13%.
2016	Resolutions n°01 and 05	State	Tariff change.	Increase of 10%. However, the tariff of shrimp farming with water adduction increased by 725%, from R$15.78 to R$130.25.
2016	Law n°16103	State	Created the contingency tariff for industrial uses. This tariff was added to the charging tariff for water resources use and had a transitory character, lasting during critical water scarcity.	
2017	Resolutions n°03 and 06	State	Tariff change and new user category: Services and Business.	Increase of 15% in all categories.
2018	Resolution n°05	State	Tariff change.	Increase of 5%, only Service and business increased by 3%.
2019	Resolution n°01	State	Tariff change.	Increase by 12%
2020	Resolution n°03	State	Classification regarding the level of water storage in hydrographic basins: ≤10% - very critical situation of scarcity; 10%–30% - critical situation; 30%–50% - alert situation; 50%–70% - comfortable level of storage; and >70% - very comfortable level of water storage. COGERH is responsible for providing information on the reservoirs. When they reach the critical situation level, a declaratory act will be issued.	
2020	Resolution n°06	State	Tariff change.	Increased by 4%

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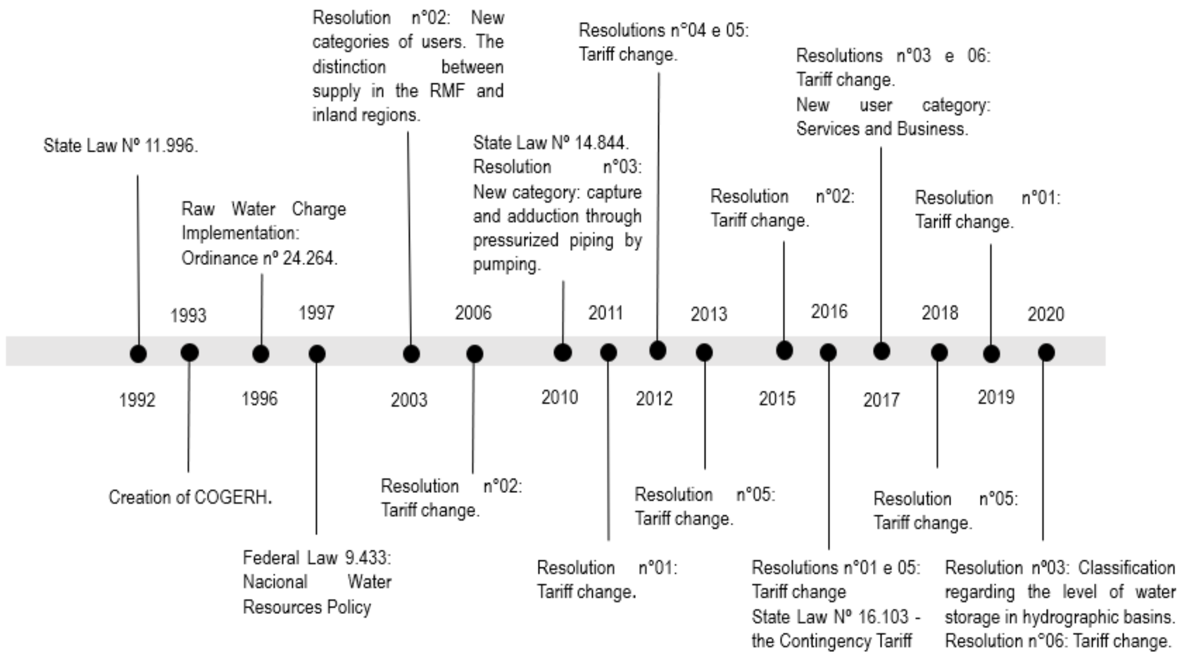

Figure 2. Raw water collection timeline.

The evolution of raw water charges in the State of Ceará started with State Law No. 11,996/92, which established this economic instrument and anticipated the Federation to enact the raw water charges in the Water Law, that is, Federal Law No. 9,433/97 (Rodrigues and Aquino, 2014). However, in 1996, charges were initiated for only three categories of users: industries; potable water service concessionaires; and users that receive pressurized, pumped, or channeled water.

Over the past 24 years, raw water charges have undergone twelve tariff changes, resulting in increases of 1505% in the Public supply and 302% in Industry categories. In addition, user categories were added: Public supply, Industry, Fish farming, Shrimp farming, Spring and drinking water, Irrigation, Service and business, and Other use.

Table 5 shows the Unit Payment Capacity (UPC) and average value of the current tariff. In the Industrial and Supply sectors, the average tariff is above the UPC. On the other hand, in the other sectors, the average value is below the UPC. Pisciculture stands out with a UPC that is 4.4 times higher than the average tariff. The same is true for Spring and drinking water. The UPC value is R$9,914.51/1,000.00m³, whereas the tariff is R$852.33/1,000.00m³, that is, the UPC is 11.6 times the tariff. Thus, the results indicate an expressive capacity to pay compared with the Water Management Company's amounts.

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Table 5. Unit Payment Capacity (UPC) and average tariff.

User Sector	UPC (R$/1,000m³)	Average Tariff (R$/1,000m³)
Public supply	91.59	283.49
Industry	1545.16	1892.21
Fish farming	147.47	33.79
Shrimp farming	320.14	96.80
Spring and drinking water	9914.51	852.33
Irrigation	26.22	13.16

Service and business values are not included in the table because this sector was added after the payment capacity study was carried out by the Secretary of Water Resources.

A positive evolution can be observed with respect to charging, creating various usage categories, and the application based on the user sector's payment capacity. However, the pricing model's improvement can be further enhanced because it is an *ad hoc* model.

Based on the analysis of the unit payment capacity of each user category, the increases are insignificant compared with the proposed value. The results of the analysis of the water collection in the study period confirm this. The growth was insufficient to meet the demands of the State Water Resource Plan.

System operation costs

The cost coverage of a river basin consists of management and investment costs. Management costs are defined as those necessary for the functioning of the water resources management system, that is, the costs of administration (ADM) and operation and maintenance (O&M). Investment costs are the costs necessary for carrying out structural and non-structural interventions in water structures.

The ADM and O&M costs correlate. The greater the number of reservoirs in an administrative region is, the greater are these costs. In addition, the storage capacity affects the O&M costs. The larger the dam is, the greater are the O&M costs.

Based on Thomas (2020), the composition of costs varies in different countries. In England, only management costs are considered. In France, the Netherlands, and in the proposals of the State of São Paulo and Paraíba do Sul River Basin, which are located in Brazil, management and investment costs are included.

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In the water resources policy of the State of Ceará, the state is responsible for investments but not responsible for charging for the use of raw water. Thus, only management costs are included in the tariff matrix and *COGERH* is responsible for implementing the management cost system. The hydrographic basins are managed by regional administrations. Their eight offices are located in the following municipalities: Fortaleza (Regional Administration of the Metropolitanas Basins), Pentecoste (Regional Administration of the Curu and Litoral basins), Sobral (Regional Administration of the Acaraú and Coreaú basins), Crateús (Regional Administration of the Serra da Ibiapaba and Sertões de Crateús basins), Quixeramobim (Regional Administration of the Banabuiú Basin), Crato (Regional Administration of the Salgado Basin), Iguatu (Regional Administration of the Upper Jaguaribe Basin), and Limoeiro do Norte (Regional Administration of the Middle and Lower Jaguaribe basins).

In addition to the regional administrations mentioned above, there are still the costs of the Head office, located in Fortaleza, and composed of important sectors for the operation of the Water Resources System of the State of Ceará, some of them are Operations Directorate, Security Management and Infrastructure, Water Resources Management, Operational Development Management.

The water and organizational infrastructures of each hydrographic basin (reservoirs, pipelines, and channels) as well as the organizational structures and the administrative apparatus are included in the cost distribution (Ceará, 2016).

The ADM costs (Figure 3) involve the administrative, managerial, and planning apparatus of the system. Thus, they include the salary, labor charges, consumables during working hours, daily allowances, transportation, tax obligations, and indemnities.

The O&M costs (Figure 4) involve the apparatus for conservation, monitoring, and operationalization of the water infrastructure including reservoirs, integration channels, pipelines, and pumping stations. In addition to maintaining these structures, we consider a water collection service for water quality analysis and electrical energy from the pumping stations. Among them, electricity costs represent a large proportion of the O&M costs of hydrographic basins.

An increase was observed in both cost categories. However, the Regional Administration of Iguatu presented an outlier difference in the administration's cost, mainly for the year 2019. Based on the collected data, we verified that this regional administration spent more than R$5 million for “Expenses due to fixed assets or write-offs.” Detailed information on these costs are not available.

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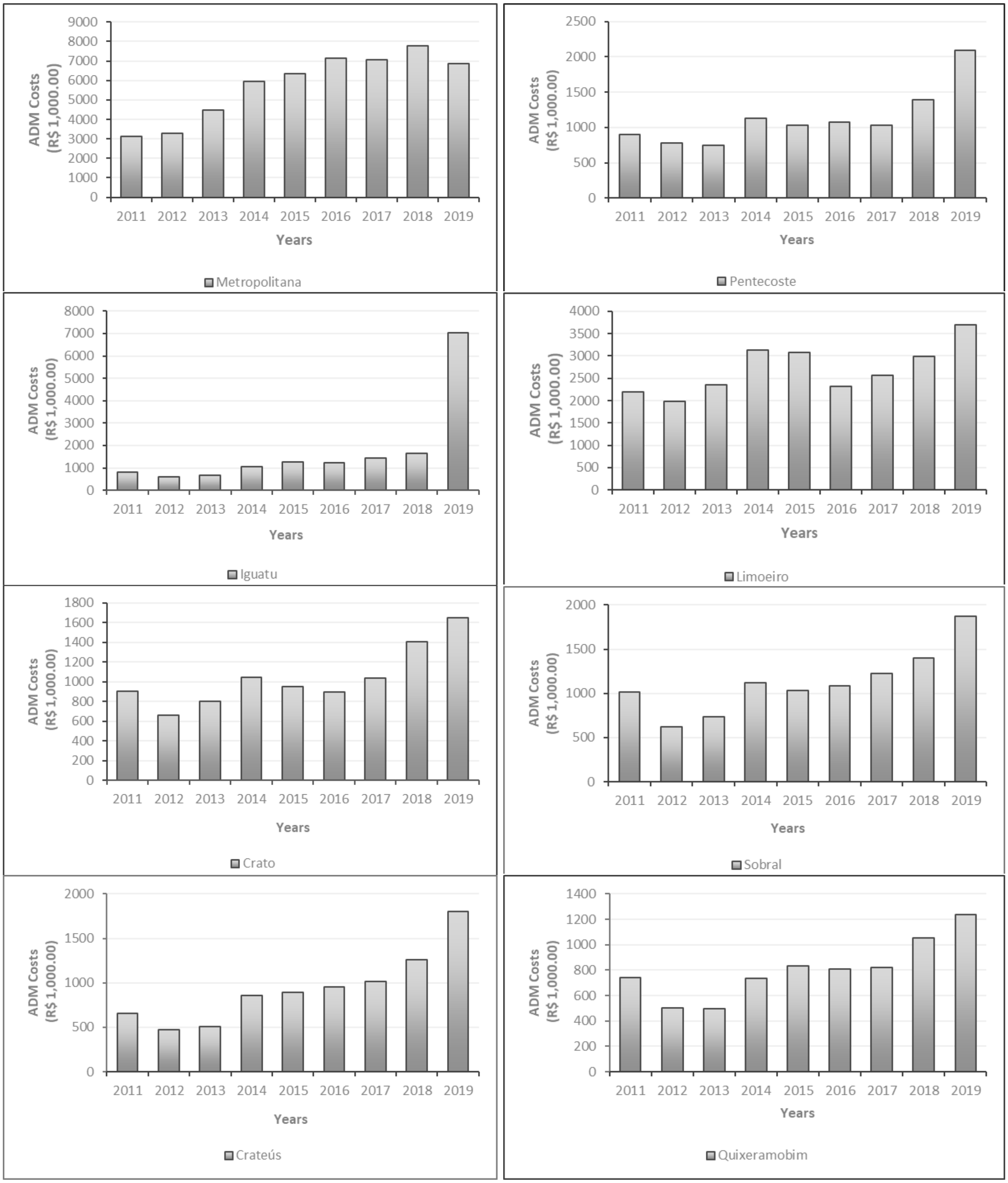

Figure 3. Administration costs of the water resources system in the State of Ceará from 2011 to 2019 (in R$1,000.00).

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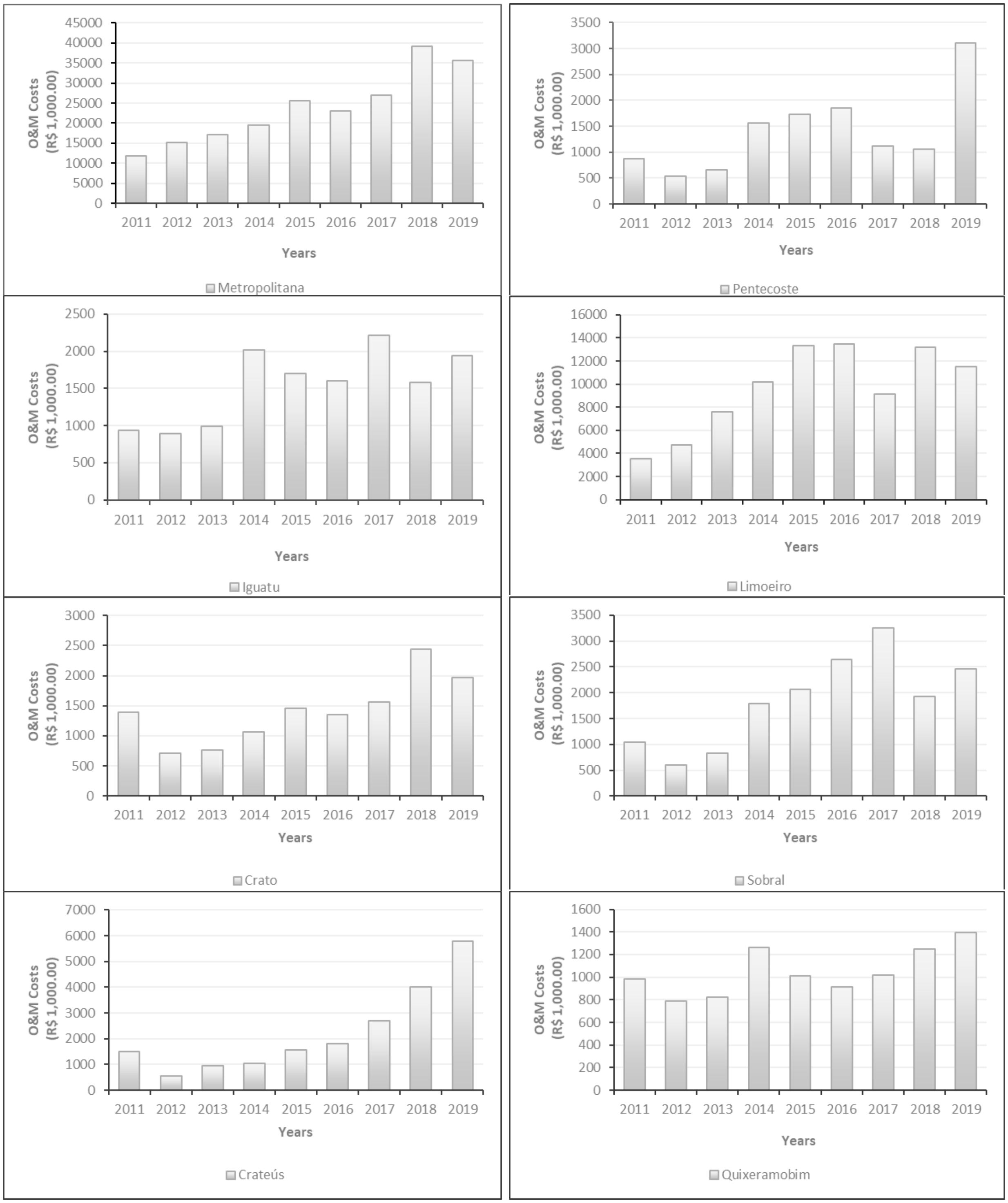

Figure 4. Operation and maintenance costs of the water resources system in the State of Ceará from 2011 to 2019 (in R$1,000.00).

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The ADM costs in Crateús and Pentecoste increased by 173% and 131%, respectively, in nine years. The same regions exhibit the highest O&M cost increase, with 287% and 224%, respectively.

We observed the lowest increases in the ADM costs of 67% and 68% in the regions Quixeramobim and Limoeiro, respectively. As for the O&M costs, we have Crato and Limoeiro's Regionals, 41% and 42%, respectively.

The highest ADM and O&M costs were observed for the Metropolitan Region of Fortaleza (MRF), which includes the state capital, Fortaleza, which is one of the ten cities with the highest contribution to the country's economy and the largest Gross Domestic Product (GDP) in the northeast (~R$67 billion; Ataliba, 2021). It lies within the limits of the Metropolitan Basin and has a demand of 13.15 m^3/s among which 1.33 m^3/s were registered for the Porto do Pecém Industrial Complex (Lôbo Neto, 2020).

Thus, it has the highest consumption in the region, requiring the water transfer from other basins to meet its demand. In addition, the MRF's main consumption is related to the industry and human supply, whereas irrigation is the sector with the largest consumption in the other regions.

From 2012 to 2018, the State of Ceará encountered the worst water crisis ever registered, considering an estimated return period of 240 yr (Pontes Filho *et al*., 2020). In 2012, the annual average rainfall ranged from 200 to 400 mm, which was below the historical average of 436 mm. From 2013 to 2017, the annual average rainfall varied between 400 and 700 mm, that is, it was within the historical average of 652 mm. In 2018, the annual average rainfall ranged from 700 to 1,000 mm, that is, it was within the historical average of 884 mm. The reservoir levels were below 12% from 2015 to 2018, which caused a limited flow of the reservoirs between 2017 and 2018.

The severity of this drought is illustrated in Table 6, which includes four states of drought (regular, pre-alert, alert, and emergency). In 2014, the reservoirs' situations overall worsened. The regions who remained in an emergency state the longest were Limoeiro, Crateús, and Quixeramobim.

The costs in the regions Pentecoste and Sobral increased in 2014, 2015, and 2016, corresponding to the emergency period of the reservoirs. The same trend was observed for Iguatu and Crato who pointed out a further cost growth in the year that entered in an emergency state.

Figure 5 shows that the managements' O&M costs and SI are negatively correlated, indicating higher costs in the most severe drought periods and the need for the implementation of measures to maintain the financial sustainability of the management system. The rows and columns in this figure refer to the SI and O&M costs of each region, respectively.

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Table 6. Status Index (SI) from 2011 to 2019.

Year	Metropolitana	Pentecoste	Iguatu	Limoeiro	Crato	Sobral	Crateús	Quixeramobim
2011	Regular	Regular	Regular	Regular	Regular	Regular	Regular	Regular
2012	Regular	Regular	Regular	Regular	Regular	Regular	Regular	Regular
2013	Pre-Alert	Alert	Regular	Regular	Regular	Pre-Alert	Pre-Alert	Regular
2014	Alert	Emergency	Regular	Regular	Regular	Emergency	Emergency	Alert
2015	Pre-Alert	Emergency	Pre-Alert	Alert	Emergency	Emergency	Emergency	Emergency
2016	Emergency	Emergency	Alert	Emergency	Emergency	Emergency	Emergency	Emergency
2017	Alert	Pre-Alert	Emergency	Emergency	Emergency	Alert	Emergency	Emergency
2018	Pre-Alert	Regular	Emergency	Emergency	Pre-Alert	Pre-Alert	Pre-Alert	Alert
2019	Regular	Regular	Emergency	Emergency	Alert	Regular	Regular	Emergency

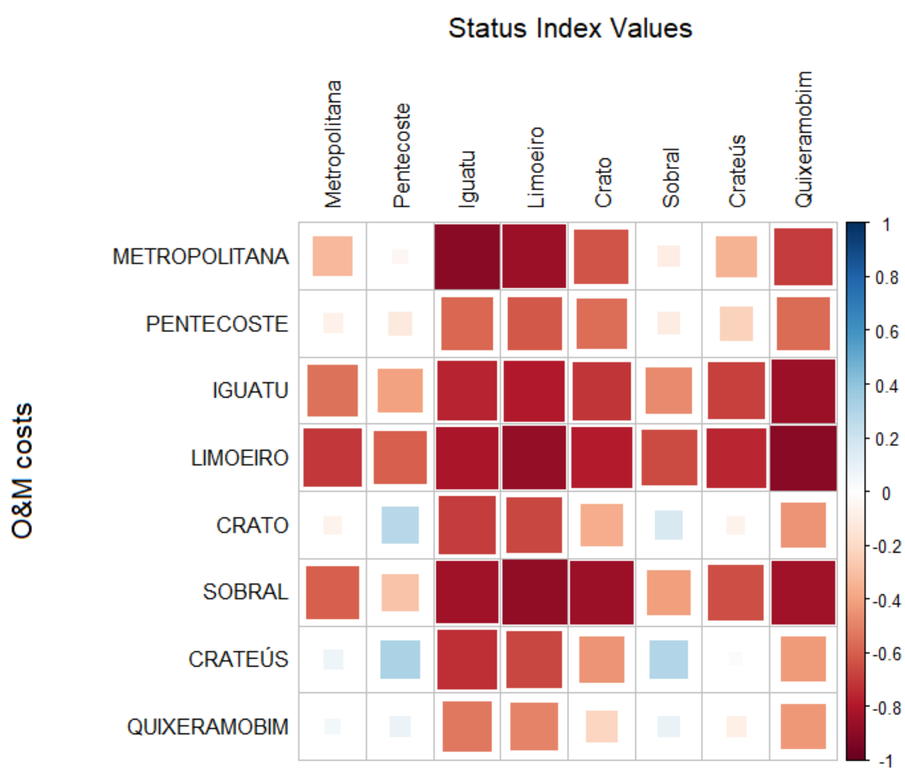

Figure 5. Pearson's correlation between the operating costs and SI.

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The increase in the costs during the drought is associated with the electricity expenditure such as electricity used for the increase in water pumping when reservoir levels are low. The intensification of the inspection of grants and consumed volumes adds to these costs. Inspections are necessary to prevent free-rider action.

Despite the drought, the average billed consumption increased between 2011 and 2014 and stabilized at ~R$78,000 from 2016 to 2019 (Figure 6).

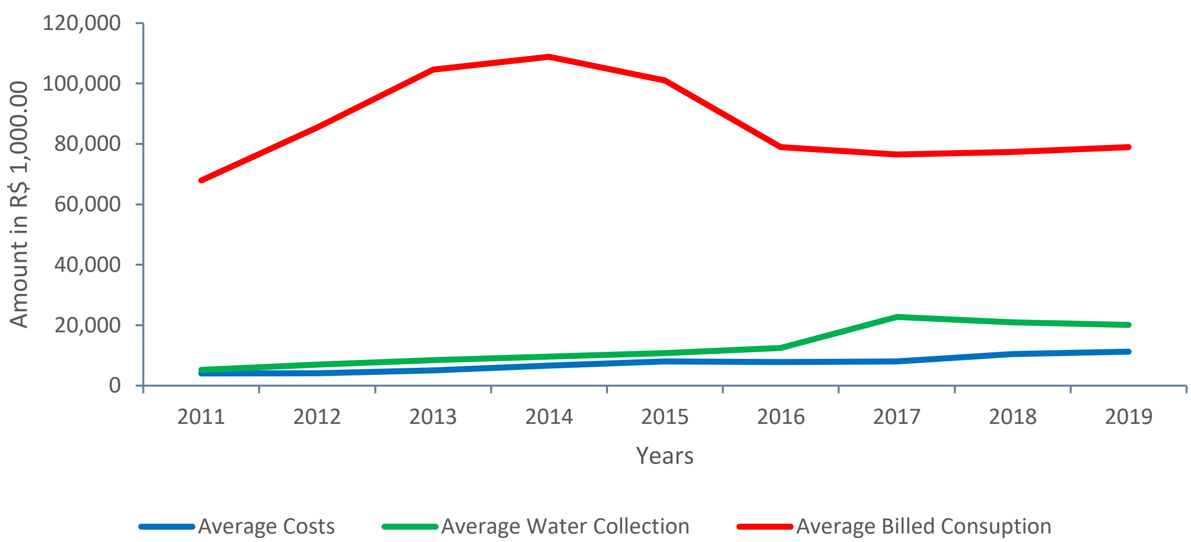

Figure 6. Average billed consumption, average water collection, and average costs from 2011 to 2019.

In addition, the trend of the water collection is similar to that of the costs, that is, it also increased over the years. However, the average water collection significantly increased in 2017 and slightly decreased thereafter.

The lowest average billed consumption and highest average unit cost were observed for Iguatu (Figure 7), leading to high management costs. In this basin, 24 of the 155 reservoirs are managed by the state. This includes Orós with a storage capacity of 1,940.00 hm^3, which is one of the main multi-annual reservoirs in the state.

We noticed that the regions with the highest average unit cost were Crateús and Iguatu. However, the regions with the most significant percentage variation were Pentecoste and Iguatu, with 585% and 220%, respectively.

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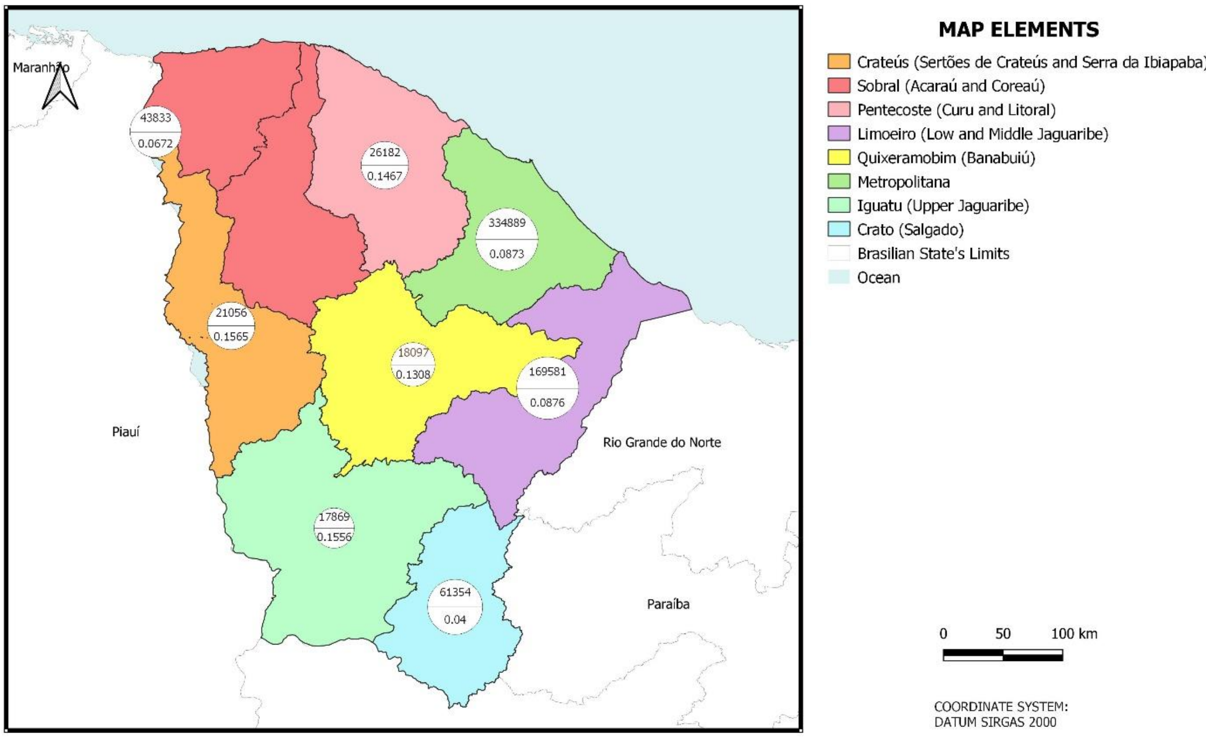

Figure 7. Average billed consumption in 1,000 m³ and average unit cost (R$) of the state management from 2011 to 2019.

As previously stated, Crateús and Pentecoste exhibited the highest percentage changes with respect to the management costs, which is reflected in the unit costs.

The region with the lowest average unit cost is Crato, which is due to the aquifers in this region, which help to reduce the invoiced consumption of raw water.

The revenue from charging for the use of raw water is summarized in Table 7. The following four regions had the highest water collection values in 2018: MRF (90%), Crato (2%), Sobral (2%), and Limoeiro (2%).

Note that, based on the Water Law nº 9,433/1997, the money collected from charging for the use of water resources will be primarily applied in the hydrographic basin in which it was collected. This law does not consider the case of basins that are supplied by the transposition of interregional or interstate water. This is the case on the MRF, with a discrepancy water collection value compared to other basins and has part of the MRF supplied by waters from the Jaguaribe region.

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Table 7. Water collection (values in R$1,000.00).

Regions	2011	2012	2013	2014	2015	2016	2017	2018	2019
Metropolitana	35,548	48,510	58,779	66,154	76,117	88,765	169,294	153,260	148,345
Pentecoste	809	766	980	1,167	1,238	1,133	1,527	1,551	1,509
Iguatu	406	458	552	757	1,002	1,119	814	876	872
Limoeiro	1,259	1,659	2,448	2,862	2,643	2,368	2,379	2,767	2,621
Crato	1,192	1,406	2,027	2,204	2,032	2,582	3,224	3,709	3,191
Sobral	1,473	1,567	1,815	2,175	2,061	2,257	2,633	2,843	2,755
Crateús	540	594	589	666	687	1,029	1,420	1,475	1,067
Quixeramobim	540	651	715	833	607	652	642	836	697
Total	41,767	55,612	67,906	76,818	86,388	99,905	181,932	167,319	161,058

Metropolitana's O&M costs are higher (R$23,763,000.00) than the sum of the O&M costs of the remaining regions (R$19,086,000.00). Also, the average ADM costs in Metropolitana are R$5,778,000, which is more than double of the costs of Limoeiro (R$ 2,702,000.00).

The average water consumption in Metropolitana is 48%, whereas that in Limoeiro is 24%. Thus, the values of the MRF significantly differ from those of other regions, indicating management difficulties associated with the transposition of basins.

Based on the State Water Resource Law nº 14,844/2010 (Ceará, 2010), the water charges must be utilized as financial resources to support studies, programs, and projects included in the Water Resource Plan.

However, the above-mentioned law also emphasizes that the expenses, including the ADM and O&M costs, must not exceed 7.5% of the total water collection. In 2019, R$161,058,000 were collected, but 7.5% of this amount equals R$12,079,000, which corresponds to 13% of the amount needed to cover the total costs (R$ 90,040,000).

Table 8 illustrates these values within the study period. It shows that the total management costs (ADM and O&M costs) cannot be covered by the annual water collection. Thus, the annual water collection is not sufficient to finance the implementation of measures, programs, and projects for the improvement of the respective basins.

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Table 8. Costs (values should be multiplied by R$ 1,000.00).

Year	Total Water Collection	7.50% of the Water Collection	Management Costs	7.5% Water Collection/Costs
2011	41,767.37	3,133.55	32,380.00	10%
2012	55,612.40	4,171.93	32,941.00	13%
2013	67,906.62	5,093.92	40,544.00	13%
2014	76,818.21	5,761.37	53,392.00	11%
2015	86,388.66	6,479.07	63,832.00	10%
2016	99,905.54	7,493.84	62,079.23	12%
2017	181,932.13	13,645.91	64,111.13	21%
2018	167,319.26	12,549.94	83,617.17	15%
2019	161,058.72	12,079.33	90,040.46	13%

Rogers *et al.* (2002) reported that this system is not sustainable and contested that the supply and O&M costs should be the minimum that is covered by the tariffs. Massarutto (2007) and Pinto & Marques (2016) suggested that opportunity costs and economic externalities should be considered in addition to the supply and O&M costs to fully recover the economic costs, also it is possible to add the environmental dimension for a full cost recovery.

Lago *et al.* (2015) and Rodrigues & Aquino (2014) suggested that the water charge should encompass nobler objectives such as a more rational use and the acquisition of management and investment resources, especially in less developed semi-arid regions, such as the State of Ceará, in which the water potential can only be realized through management and investment in water storage and transfer. Based on our case study, the water charges in Ceará are mainly used to cover O&M costs, without much success, and the investments can be considered as sunk costs. Schuerhoff *et al*. (2013) pointed out that it is difficult to design a policy that balances the objective of obtaining revenue with behavior change such that the revenue does not have a Ramseyan meaning.

Pinto et al. (2021) reported that the water tariffs play important roles in resource-stressed environments in which the competing uses, resource availability, and infrastructure constraints must be considered.

Based on Ferreira *et al.* (2020) and Cerqueira (2019), the cubic meter prices of raw water charged in Brazil remain extremely low. They are insufficient to meet the demands presented in the National Water Resource Plan and do not efficiently stimulate the rational use of water (ANA, 2014).

Cerqueira (2019) discussed two solutions regarding the lack of resources: increasing the legal limit (7.5%) through law or increasing the water collection fee. They assumed that the increase in the tariff will increase the resistance of users because an increase in the legal limit would increase unnecessary expenses.

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The GDP of Brazil in 2019 was R$7,389,131 million, whereas that of Ceará was R$163,575 million. Ceará occupies the twelfth position in the country and the third in the northeast region. However, considering the GDP per capita, Ceará is in place 22, demonstrating that it is a great challenge to overcome the low income in the country (IPECE, 2021).

The economy of Ceará comprises three major sectors: agriculture, industry, and services. The agricultural sector is divided into activities related to agriculture, livestock, fish, and plant extraction. Raw water is consumed in the production processes related to these activities (Soares et al., 2021). Among these sectors, the consumption of raw water is the highest in agriculture in Ceará, with 60.1%, whereas the service sector accounts for 32.6% of the water consumption, followed by the industry (7.2%; Soares et al., 2021). However, the least water is consumed in the sector that pays the highest tariff, that is, the industry, whereas the fees paid by the largest consumer of water, that is, agriculture/irrigation and fish farming, are the smallest. In addition, the industry contributes 17.05% to Ceará's GDP, whereas the agriculture contributes 22.65%, leaving 69.82% for the service sector, which was not included in the analysis in this study. Therefore, the agricultural sector significantly contributes to the GDP, with a marginal growth in the tariff value.

Challenges of raw water charges

In the context of water scarcity, international organizations and academics claim that water pricing can significantly improve the management of water resources and that economic, environmental, and social objectives can be achieved by optimal tariff design (García-Rubio *et al.*, 2015).

The results of the analyzes carried out for Ceará State show that the charges for raw water are mainly used to cover the management costs but are insufficient to subsidize studies, projects, and water management programs. Therefore, it is necessary to reassess the tariff, which is considered to be a public price. The low tariffs defined in the collection policy do not promote the more rational use of water by users (Libanio, 2018; Berbel *et al*., 2019; Rey *et al.,* 2019).

It is necessary to assess whether the pricing policy, that is, if the tariff meets the social criteria of accessibility, justice, and equity, in addition to economic efficiency, environmental sustainability and public acceptance and transparency (García-Valiñas, 2005; Donoso, 2017).

The ability to pay was determined to verify if some of the objectives were satisfied. The results show that users, such as shrimp farming, irrigation, and fish farming, have an expressive capacity to pay the amounts charged.

Based on the current charging model in the State of Ceará, an average tariff is charged, that is, the collected amount does not vary depending on water availability. This means that the amount collected in periods of scarcity in which the operating costs are higher than usual is the same as that

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in non-scarcity periods. This results in financial fragility of the management institution and, consequently, in the unsustainability of the water resources management system. A scarcity-based tariff would reflect the basin's drought conditions and thus would be more appropriate for Brazil's semi-arid northeastern part (Araújo *et al*., 2019).

Increasing the sustainability and efficiency of this system are challenges for the raw water charge instrument. We suggest restructuring the pricing model to incorporate a floating rate considering the drought severity such that the raw water charges are based on the water supply and demand. In addition, it is important to establish a scarcity coefficient that considers the water availability and is used to determine the tariff. Based on this coefficient, users must feel coerced to reduce their consumption in times of scarcity and/or be willing to pay more for the resource. However, this process must be endowed with legitimacy and acceptance and must be guided by different stakeholders to avoid divergence between policy design and management practice (Berbel *et al*., 2019; Libanio, 2018).

Thus, the floating tariff would reflect the drought states of a hydrographic basin and could trigger the change in the user behavior with respect to water consumption. The drought states have been defined by Resolution No. 3/2020 based on the classification of the reservoir storage in an extremely critical situation of water scarcity: critical, alert, comfortable, and very comfortable.

Conclusion

In this study, the evolution of raw water in the State of Ceará was analyzed and cost analysis was conducted to answer the two following questions: does the water collection fulfill its function of financing the water resources system? Is the pricing model flexible and absorb the effects of climate variability?

We observed that the annual water collection cannot cover all management costs and is not sufficient to finance the implementation of measures, programs, and projects necessary to improve the water management in the basins.

The correlation between the increase in costs and the drought severity shows that it is necessary to establish a tariff model in which the effects of climate variation are considered.

The challenge is to develop a floating tariff that is related to the water scarcity and incorporates the effects of climate variability.

In the State of Ceará, the billed consumption in different regions and subsystems differs. This indicates that the regions' peculiarities should be considered in the establishment of water charges and the allocation and/or reallocation of water between hydrographic basins and/or subsystems should be promoted.

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Acknowledgments

The authors thank the Conselho Nacional de Desenvolvimento Científico e Tecnológico - Brasil (CNPq), the Coordenação de Aperfeiçoamento de Pessoal de Nível Superior (CAPES) and the Fundação Cearense de Apoio ao Desenvolvimento Científico e Tecnológico (FUNCAP), Project nº 11098079/2019.

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