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CHARGES FOR THE USE OF RAW WATER: AN ANALYSIS OF THE PERFORMANCE OF MODELS APPLIED IN WATERS UNDER FEDERAL DOMAIN IN THE *CUREMA-MÃE D'ÁGUA WATER* SYSTEM

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ABSTRACT

Aiming to explore the potential fundraising, models used for charging the raw waters of São Francisco, Paraíba do Sul, and Doce rivers were applied and evaluated in the Curema-Mãe D'Água water system, located in semiarid Brazil. The methodology consisted of a bibliographical review, documentary research, system operation modeling, application of models, and critical analysis of operations and collections results, comprising a total of 240 months from 2002 to 2021. When applying the Standard Operational Policy (SOP), the water system did not meet the demands 35.4% of the time. The model with the highest collection was the one used in Paraíba do Sul River (R$ 12.71 million/year). The models applied in São Francisco (R$ 1.37 million/year) and Doce Rivers (R$ 3.58 million/year) presented the lowest collections. The Paraíba do Sul River model provided the highest charging with water abstract and consumption elements. The Doce River model, conversely, delivered the highest values through the effluent discharge element. The analysis of charging results indicates that each model has specific applications and outcomes. None of the models consider eventual water scarcity conditions in their formulations.

Keywords: Collection. Water basin committee. Unit public price. Water charging mechanism. Semiarid.

COBRANÇA PELO USO DA ÁGUA BRUTA: UMA ANÁLISE DA APLICAÇÃO DE MODELOS PRATICADOS EM ÁGUAS DE DOMÍNIO FEDERAL NO SISTEMA HÍDRICO CUREMA-MÃE D'ÁGUA

RESUMO

Com o objetivo de explorar o potencial de captação de recursos, foram aplicados e avaliados modelos de cobrança das águas brutas dos rios São Francisco, Paraíba do Sul e Doce no sistema hídrico Curema-Mãe D'Água, localizado no semiárido brasileiro. A metodologia consistiu em revisão bibliográfica, pesquisa documental, modelagem do funcionamento do sistema, aplicação de modelos e análise crítica dos resultados das operações e cobranças, compreendendo um total de 240 meses de 2002 a 2021. Ao aplicar a Política Operacional Padrão (POP), o sistema de água não atendeu a demanda em 35,4% das vezes. O modelo com maior arrecadação foi o utilizado no Rio Paraíba do Sul (R$ 12,71 milhões/ano). Os modelos aplicados no São Francisco (R$ 1,37 milhão/ano) e nos rios Doce (R$ 3,58 milhões/ano) apresentaram as menores arrecadações. O modelo do Rio Paraíba do Sul proporcionou a maior carga com captações de água e elementos de consumo. Já o modelo do Rio Doce apresentou os maiores valores pelo elemento de descarga de efluentes. A análise dos resultados da cobrança indica que cada modelo tem aplicações e resultados específicos. Nenhum dos modelos considera eventuais condições de escassez de água em suas formulações.

Palavras chaves: Arrecadação. Comitê de bacia. Preço público unitário. Mecanismo de cobrança. Semiárido.

INTRODUCTION

Conflicts over water use are increasingly evident, manifested in the difficulties in obtaining water, both in quality and quantity, to meet the growing demands. There may be disagreements among multiple water users, making it a crucial resource to manage and regulate. It is then necessary to provide the sustainability of the tripod of needs - economic, social, and environmental -, while promoting current and future harmony between uses (MELLO & JOHNSON, 2016; AMÉRICO-PINHEIRO et al., 2019; PEIXOTO et al.,2019; BRITO & AZEVEDO, 2020; PICOLI, 2020).

Brazil has undergone demographic and economic transitions due to industrialization and urbanization. Such changes put enormous pressure on natural resources, especially water. Recent data shows that activities aimed at economic and population growth were incompatible with the interests of preserving natural resources (BRAGA JUNIOR et al., 2021). The inadequate water supply for multiple purposes directly impacts human lives and national economies, so it is necessary to find alternatives that may help solve these problems (ROSA & GUARDA, 2019). In this context, the growing demand for water resources, along with the frequent periods of drought and the pollution of water bodies in the semi-arid region of Brazil, has caused numerous environmental problems over the last few decades. Furthermore, the rains show a great interannual irregularity, generally occurring within four months (RODRIGUES & LEAL, 2019). Due to this irregularity, the water supply in the region comes from reservoirs, which are subject to evaporation losses and watershed management practices (NUNES et al., 2019).

The Water Resources National Policy (PNRH, from the Portuguese abbreviation), instituted by Law nº 9.433 on January 8th, 1997 (later Water Law), created the National Water Resources Management System (SINGREH, from the Portuguese abbreviation) and established instruments for the administration of water resources at the national level (bodies of water in regions spanning two or more states or borders, or stored in structures made with federal government resources), including water use charging. The PNRH innovates with a participatory model by establishing river basin committees that bring together public authorities, users, and civil society. It is a modern law that enables conditions for solving conflicts regarding water use (ANA, 2019a; SILVA, 2020).

Charging for the use of water resources aims to: “recognize water as an economic good and give users an indication of its real value; encourage rational use of water; obtain resources to finance programs and interventions contemplated in the water resources plans” (BRASIL, 1997).

Many authors proposed charging models for raw water use in basins regulated by the federal government, such as the *São Francisco*, *Paraíba do Sul*, and *Doce* rivers basins” (ANA, 2014; ANA, 2022a; ANA, 2022b).

ANA (2016) and Bezerra et al. (2022) evaluated, by using different methodologies, the charging model used for the waters of the São Francisco River in one of the major water systems of the *Piancó-Piranhas-Açu* river basin, the *Curema-Mãe D’Água* water system. The authors verified the infeasibility of installing and maintaining a water basin agency with the resources obtained from the collection. Given the geographical context, the model employed in the *São Francisco* River basin was expected to closely align with the environmental, social, and economic realities observed in the studied system. Consequently, one objective of this paper is to investigate if other models applied to waters under federal domain may be relevant for water charging in the *Coremas-Mãe D'Água* system.

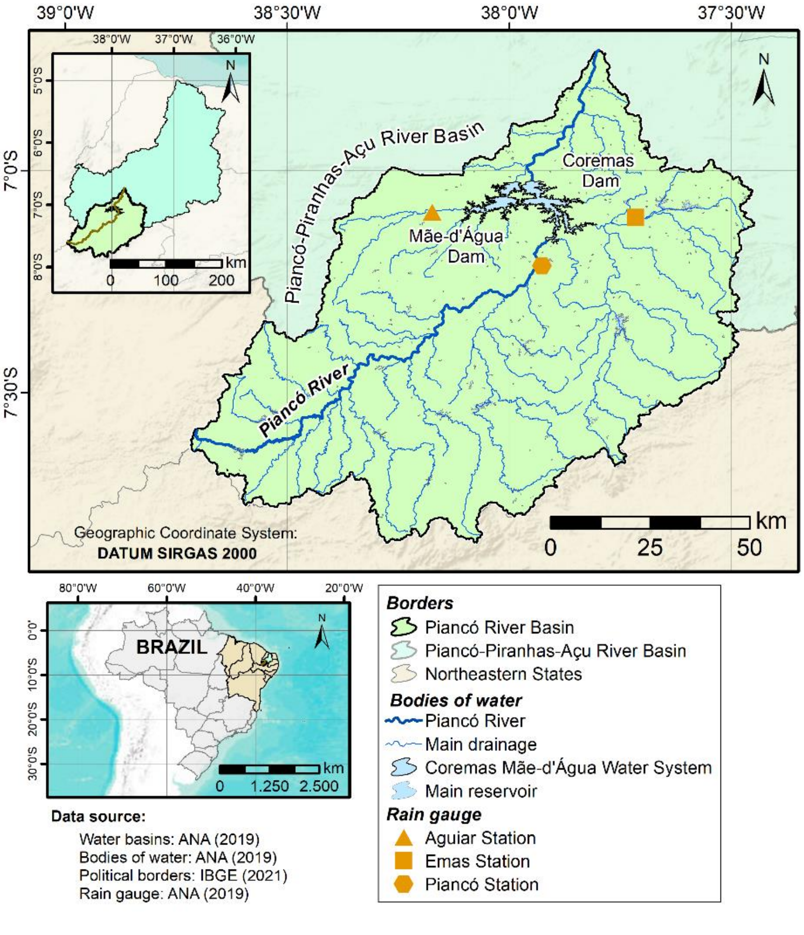
Aiming to explore the revenue potential in the *Curema-Mãe D'Água* reservoir, considering a monthly operation, this research innovates by applying and analyzing two more charging models: those used for the waters of *Paraíba do Sul* and *Doce* rivers, Brazil. Furthermore, the operational sustainability of the system and the performance of the charging models are evaluated over the period from 2002 to 2021, which encompassed one of the most significant droughts recorded in the region, occurring between 2012 and 2017.

METHODOLOGY

Study Area

The *Piancó* River basin comprises, along with seven other sub-basins, the *Piranhas* River Basin, also known as *Piancó-Piranhas-Açu*, which is in the extreme southwestern of the state of *Paraíba*, between the latitudes 6°43’51’’S and 7°58’15’’S and the longitudes 37°27’41’’W and 38°42’49’’W. It borders the Upper and Middle *Piranhas* Basins to the north, *Pernambuco* State to the south, the *Espinharas* River Basin to the east, and *Ceará* State to the west. The water basin covers 9,228 km². The length of the *Piancó* River, which is the major watercourse, is 208 km. Figure 1 shows the location of the *Piancó* River basin (PERH/PB, 2006; PRH/ PIANCÓ-PIRANHAS-AÇU, 2016).

Figure 1- Location of *Piancó* River Basin.



Source - Data from ANA, 2019; IBGE, 2021.

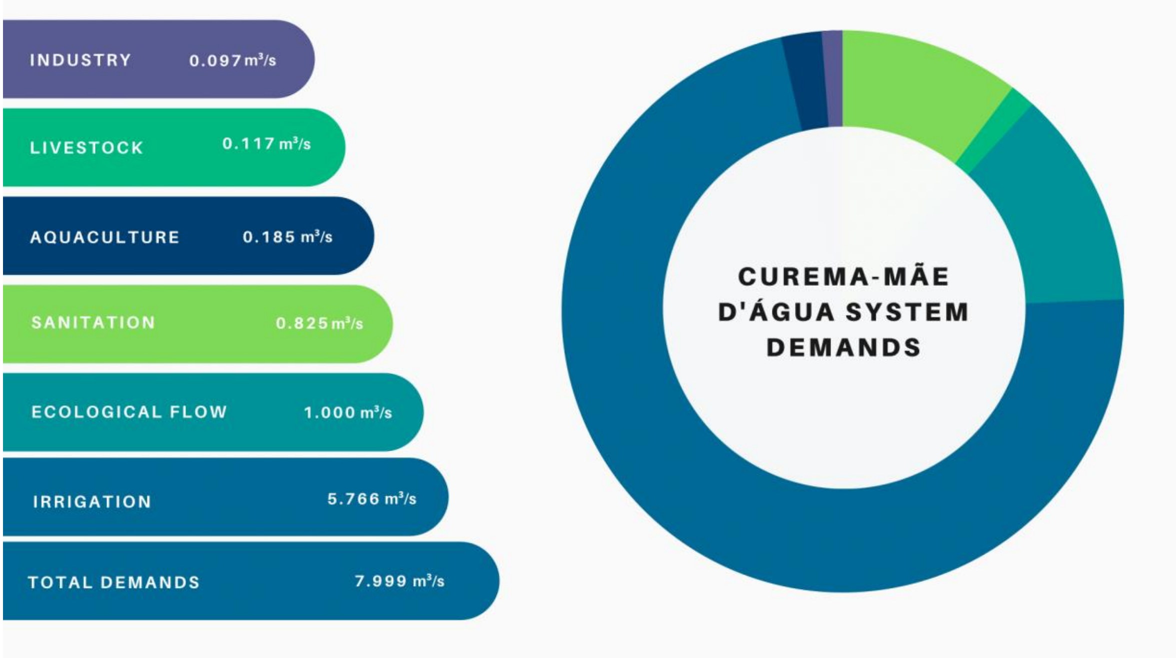
According to *Paraíba* Water Resources General Plan – PDRH/PB (SCIENTEC, 1997), the *Piancó* River basin consists of about 1,336 dams, with 90.6% classified as small reservoirs. The largest water reserve in *Paraíba* - the *Curema-Mãe D'Água* dams - is in this basin, with a combined capacity of 1,159.0 hm³ (ANA, 2014). An open channel with 12 m³/s capacity links the reservoirs.

As in Celeste et al. (2009), Bezerra (2018), and Bezerra et al. (2022), we simplified the mathematical implementation of the *Curema-Mãe D'Água* system by considering the two reservoirs as just one (equivalent reservoir). According to the Joint Technical Note Number 02/2014/SRE/SUM-ANA (ANA, 2014), the maximum volume was calculated using data obtained by bathymetry. Therefore, this study assumes the minimum and maximum capacities of the equivalent reservoir as 46.8 hm ³ and 1.159,0 hm³, respectively.

The inlet flow for the equivalent reservoir corresponds to the sum of the inflows to each dam, obtained from the flow measurement stations of Piancó, Emas, and Aguiar. Monthly records from 2002 to 2021 come from the HidroWeb Portal (ANA, 2022c). Lima (2004) provided monthly evaporation and precipitation data.

The main demands of the water system are human supply (sanitation), livestock, ecological flow downstream of the dams, irrigation, aquaculture, and industry (ANA, 2004; ANA, 2016). Figure 2 lists the demands used in this study.

Figure 2 - Demands in the *Curema-Mãe d'Água* Water System.



Source - Made from data of ANA, 2004; ANA, 2016.

Water System Operation

Following the studies by Bezerra et al. (2022) and applying their methodology to assess new models, this study used the Standard Operating Policy (SOP) to carry out the water balance. For this purpose, we considered historical series of monthly inflows.

The SOP model is a water release rule that consists of applying two basic assumptions (Loucks *et al*., 1981):

1. When the available water is equal to or less than the demand, release the available volume.
2. When the available water exceeds the water need, attend to the demand and accumulate the surplus in the reservoir until it reaches its maximum volume and spill starts.

The allocations and volumes of each period were related to current inflow, evaporation, precipitation, and spillage by the continuity Equations (1) and (2):

$$S_{(1)} = S_{(0)} + Q_{(1)} - R_{(1)} - E_{(1)} + P_{(1)} - Sp_{(1)} \quad (1)$$

$$S_{(t)} = S_{(t-1)} + Q_{(t)} - R_{(t)} - E_{(t)} + P_{(t)} - Sp_{(t)};\ \forall_t \quad (2)$$

In which $S_{(t)}$ is the volume of the reservoir at the end of the month *t*; $S_{(0)}$ is the initial volume; $R_{(t)}$ is the volume allocated to all uses during month *t*; $Q_{(t)}$ is the inflow to the system during month *t*; *E*(*t*) is the evaporation over the liquid surface of the reservoir during month *t*; $P_{(t)}$ is the precipitation over the liquid surface of the reservoir during month *t*; e $Sp_{(t)}$ is the spillage that may occur during month *t*.

The physical constraints of the water system define the limits for allocations, volume, spillage, evaporation, and precipitation, according to Equations (3) to (5).

$$0 \leq R_{(t)} \leq D_{(t)};\ \forall_t \quad (3)$$

$$S_{min} \leq S_{(t)} \leq S_{max};\ \forall_t \quad (4)$$

$$Sp_{(t)} \geq 0;\ \forall_t \quad (5)$$

where $D_{(t)}$ is total demand of the system, and S_{max} and S_{min} are the maximum and minimum volumes of the reservoir, respectively.

Silva (2017) also used this methodology to describe and understand the use of water in the system that connects the Engenheiro Ávidos and São Gonçalo reservoirs, through data collection and construction of a simulation model using *Matrix Laboratory* (MATLAB), version R2013.

Charging Models for the Use of Raw Water

The charging models for the River Basin Committees of *São Francisco* (CBHSF) and *Paraíba do Sul* (CEIVAP) rivers include the withdrawal, consumption, and organic load discharge, according to deliberations Number 94/2017-CBHSF and Number 218/2014 -CEIVAP, respectively. Deliberation Number 69/2018 contains the guidelines for the charging model in the *Doce* River Basin (CBH-Doce). Table 1 presents the equations for the charging models used in each basin.

Table 1 - Equations used in the charging models of *São Francisco*, *Paraíba do Sul* and *Doce* rivers.

(To be Continued)

São Francisco River	**Paraíba do Sul River**	**Doce River**
$Vcap = Qcapout \cdot PPUcap \cdot Kcap$ (*when there is no measurement of the annual volume withdrawn*)	$Vcap = Qcapout \cdot PPUcap \cdot Kcapclasse$	$Vcap = Qcap \cdot PPUcap \cdot Kcap$
$Vcap = \{Kout \cdot Qcapout + Kmed \cdot Qcapmed + Kmedextra \cdot [0{,}70 \cdot (Qcapout - Qcapmed)]\} \cdot PPUcap \cdot Kcap$ (*when the annual volume withdrawn is measured*)	$Vcap = \{Kout \cdot Qcapout + Kmed \cdot Qcapmed + Kmedextra \cdot [0{,}70 \cdot (Qcapout - Qcapmed)]\} \cdot PPUcap \cdot Kcapclasse$ (*when the annual volume withdrawn is measured*)	$Vcap = Qout \cdot PPUcap \cdot Kcap$
$Kcap = Kclasse \cdot Kef \cdot Krural$	$Kcapclasse - will\ be\ defined\ based\ on\ the\ cla$	$Kcap = Kcapclasse \cdot Kt$
$Kef = K_0$	$V_{Agropec} = (Valor_{Cap} + Valor_{Cons}).K_{Agropec}$	-
$Kef = Ksist \cdot Kman$	-	-
$Kef = Kmansolo \cdot Kmanirri$	$Vcon = (QcapT - QlançT) \cdot PPUcon \cdot (Qcap - QcapT)$	-
$Kef = K_0$	$V_{Agropec} = (Valor_{Cap} + Valor_{Cons}).K_{Agropec}$	-
$Vcon = Qcon \cdot PPUcon \cdot Kcon$	$Vcon = Qcap\ .PPUcon \cdot Kcon$ *(Irrigation)*	-
$Kcon = Kcap$	$QcapT = Qcapmed$ or equal to $Qcapout$ (*if there is no measurement, in bodies of water under the administration of the Union and the states, plus those withdrawn directly in networks of concessionaires of water distribution systems*)	-
$Qcon = Qcap– - Qlan$	$Qcap = Qcapmed$ *or equal to* $Qcapout$ *(if there is no measurement, by domain*)	-
$Qcon = Qcap \cdot Kconirr \cdot Kcon$		
$Vlan = Qind \cdot PPUlan \cdot Klan$	$VDBO = COBOD \cdot PPUBOD$	$Vlan = EPL \cdot PPU_{EP}$
$Qind = Qdil + Qlan$	$COBOD = COBOD \cdot QlanFed$	-

Table 1 - Equations used in the charging models of the *São Francisco*, *Paraíba do Sul* and *Doce* rivers.

(Conclusion)

***São Francisco* River**	***Paraíba do Sul* River**	***Doce* River**
$Qdil = Qef \cdot \frac{(Cef - Cperm)}{(Cperm - Cnat)}$	-	-
$Vpch = 0{,}0075 \cdot GH \cdot TAR$	-	$Vpch = EH \cdot GH \cdot K$
$Vtran = (Qcap \cdot PPUcap + Qcon \cdot PPUcon) \cdot Kclass \cdot Kprio$	$V_{transp} = V_{total} \,.\, 1{,}15$	$Vtran = Qtransp \cdot PPUtransp \cdot Kclasse$
-	-	$EP = CP_{(DBO,STT,PT)}/CPC$
-	-	$PPU_{EP} = CPC_{DBO} \cdot PPU_{lan}$

Source - Deliberation Number 218/2014-CEIVAP, 94/2017-CBHSF and 69/2018-CBH-Doce.

Chart 1 presents the description of the variables established in the equations for calculating charges for withdrawing, consuming and releasing effluents (Table 1).

Chart 1 – Description of variables used in charging models.

(To be Continued)

Variable	Description	Unit
$Value_{Cap}$	Annual amount charged for water abstraction.	R$/year
$Value_{release}$	Annual amount charged for the effluents release	R$/year
$Q_{Cap\ out}$	Annual volume of water, according to the grant value or verified by the granting body.	m³/year
$PPU_{\text{catcthmen}}$	Unit Public Price for superficial withdrawal.	R$/m³
K_{cap}	Coefficient that considers the objectives to be achieved with the collection of water	Dimensionless
$K_{cap\ classification}$	Coefficient that considers the classification class of the water body where there is water withdrawal	Dimensionless
$Value_{cons}$	Annual amount charged for consumption	R$/year
Q_{cons}	Annual volume of water consumed	m³/year
Q_{capT}	Total annual volume of water withdrawal	m³/year
Q_{cap}	Annual volume of water withdrawal	m³/year
$Qout$	Annual volume of granted water	m³/year
$Q_{release}$	Total annual volume of released water in bodies of water under the administration of the States or Union	m³/year
$PPU_{\text{Consumption}s}$	Unit Public Price for water consumption	R$/m³
K_{cons}	Coefficient that considers the objectives to be achieved by water consumption charge	Dimensionless
K_{ef}	Coefficient that considers water use efficiency	Dimensionless

Chart 1 - Description of variables used in charging models.

(Conclusion)

Variable	**Description**	**Unit**
$K_{consumption}$	Coefficient that considers the part of the water used in irrigation that does not return to the water bodies	Dimensionless
$Q_{unavailable}$	Appropriate annual flow in the watercourse for the dilution of effluents released into the water body	m³/year
$PPU_{release}$	Unit Public Price for water made unavailable	R$/m³
$K_{release}$	Coefficient that considers the objectives to be achieved by charging for the release of effluents	Dimensionless
$Valor_{BOD}$	Annual payment for the organic load release	R$/year
CO_{BOD}	Annual load of $BOD_{5,20}$ (Oxygen biochemical demand after 5 days at 20°C) effectively loaded	Kg/year
PPU_{BOD}	Unity Public Price for the release of organic load	R$/kg
EPL	Limiting Population Equivalent	Inhabitants
PPU_{EP}	Unity Public Price referred to an EPL	R$/Inhab
$Value_{farming}$	Annual payment for withdrawal and consume of water for users in the agriculture and aquaculture sectors	R$/year
$K_{farming}$	Coefficient that considers good practices in the use and conservation of water on the rural property where water resources are used	Dimensionless
$Q_{lancFed}$	Annual volume of water released, according to measurement data or, in the absence of this, according to data granted, or by verification of the granting body in the process of regularization	m³/year
Kt	Coefficient that considers the nature of use and/or good	Adimensional

	practices in water use and conservation.	
EP	Population Equivalent, in inhabitants;	Adimensional
$CP_{(BOD,STT,PT)}$	Polluting Load, for each variable (BOD, SST and PT)	Kg/year
CPC	*Per Capita* Load	Kg/hab/year
CPC_{DBO}	Per Capita Load (CPC) referring to the DBO variable	Kg/hab/year

Source - Resolutions Number 218/2014-CEIVAP, 94/2017-CBHSF and 69/2018- CBH-Doce .

Operational Criteria

This study considered the following operational criteria:

1) The period used to simulate the system covered 20 years (2002 - 2021), that is, 240 months.

2) The priorities to meet demands must be in the following order: human supply (sanitation), livestock, ecological or minimum flow downstream of the dams, irrigation, aquaculture, and industry.

3) The initial volume of the reservoir was 40% of its maximum capacity (Bezerra et al., 2022).

4) Water returns from agriculture and aquaculture were both considered zero. For supply (sanitation), livestock, and industry, we assumed the returns equal 80% of the amounts collected.

5) The values of BOD of the sewage are 300 mg/L for human and livestock supply. For industry, 2.000 mg/L.

6) The values for the collection coefficients, displayed in Tables 2, 3, and 4, were according to the framework of the Piancó River (assumed as Class II) and based on the experience observed in the *São Francisco* (CBHSF, 2008) and *Paraíba do Sul* water basins.

7) The values of public prices practiced in *São Francisco*, *Paraíba do Sul*, and *Doce* river basins (Table 5), are as determined in the Resolution of the National Water Resources Council Number 192/2017 (CNRH, 2017).

8) The models were developed in GNU Octave 7.1.0.

Table 2 - Charge coefficients used for the *Curema-Mãe d'Água* System considering the charge model for the *São Francisco* river basin.

User	*Kt*	*Kcap*	*Kcon*	*Klan*	*Kcla*	*Kconirr*
Sanitation	1	1	1	1	1	-
Livestock	0.025	0.025	0.025	1	1	-
Minimum flow	1	0	0	0	1	-
Irrigation	0.025	0.025	0.025	1	1	0.8
Aquaculture	0.025	0.025	0.025	1	1	-
Industry	1	1	1	1	1	-

Source - Deliberation Number 94/2017-CBHSF

Table 3 - Charge coefficients used for the *Curema-Mãe d'Água* System considering the charge model for the *Paraíba do Sul* river basin.

User	***Keco***	***Kagropec***	***Kpd***	***Klan***	***Kcapclasse***	***Kconirr***
Sanitation	-	1	1.1	1	0.9	-
Livestock	-	0.5	0	1	0.9	-
Minimum Flow	0	0	0	1	0	-
Irrigation	-	1	0	1	0.9	0.95
Aquaculture	-	0.5	0	1	0.9	-
Industry	-	1	1.1	1	0.9	-

Source - Deliberation Number 218/2014-CEIVAP.

Table 4 - Charge coefficients used for the *Curema-Mãe d'Água* System considering the charge model for the *Doce* River basin.

User	***Kt***	***Kcap***	***Kgestão***	***Klan***	***Kcapclasse***	***Kconirr***
Sanitation	1	1	1	-	1	-
Livestock	0.05	0.05	1	-	1	-
Minimum Flow	0	0	1	-	1	-
Irrigation	0.05	0.05	1	-	1	-
Aquaculture	0.05	0.05	1	-	1	-
Industry	1	1	1	-	1	-

Source - Deliberation Number 69/2018- CBH-Doce.

Table 5 - Public prices used for simulation in the *Curema-Mãe D'Água* System.

Type of Use	**PPU**	**Value CBHSF**	**Value CEIVAP**	**Value CBH-Doce**
Water Catcthmen	$PPU_{\text{catcthmen}}$	R$ 0.0151 / m³	R$ 0.0294 / m³	R$ 0.0526 / m³
Water Consumption	$PPU_{\text{Consumptions}}$	R$ 0.0302 / m³	R$ 0.0588 / m³	-
Flow effluents	$PPU_{release}$	R$ 0.0015 / m³	R$ 0.2058 / kg de BOD	R$ 0.2804 / Kg

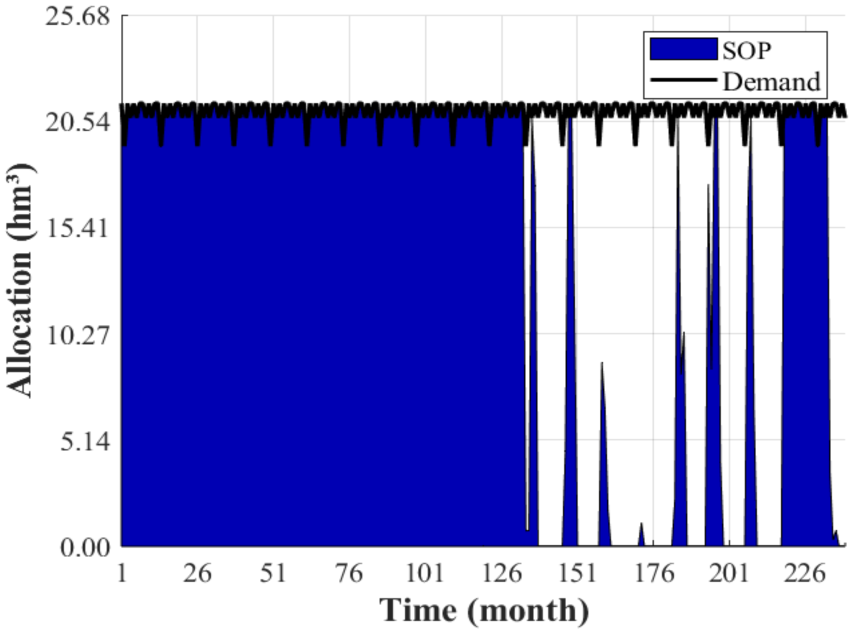
Source - ANA, 2023.

RESULTS AND DISCUSSION

The SOP operation policy and the charging models for using raw water were applied to the Curema-Mãe D'Água water system and analyzed from the perspective of water sustainability and the potential for collection.

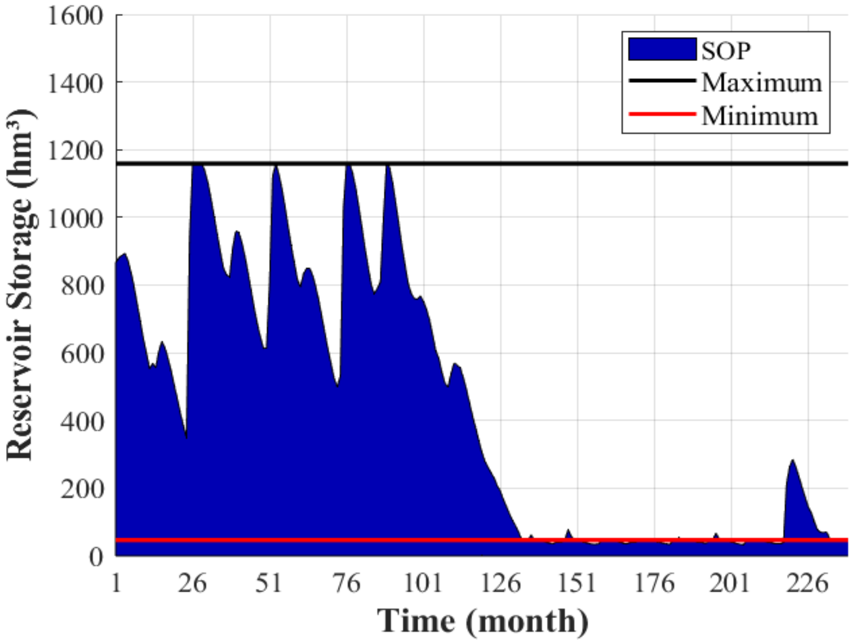
This investigation assumed as a priority the meeting of demands for human supply (sanitation) and animal watering was a priority. Figures 3 and 4 show the behavior of water allocation (sum of uses considered) and the equivalent volume of the reservoir during the study period.

Figure 3 - Water allocations for all uses (2002-2021).



Source - Author *et al.*, 2023.

Figure 4 - Behavior of the equivalent reservoir volume (2002-2021).



Source - Author et al., 2023.

The results presented in Figures 3 and 4 proved that the system did not meet the demands in eighty-five of the 240 verified months. The model also confirmed the 2012-2017 drought, well reported by AESA (2021). Considering the current demands and the system operation by SOP, water sustainability and collection were compromised in 35.4% of the analyzed months.

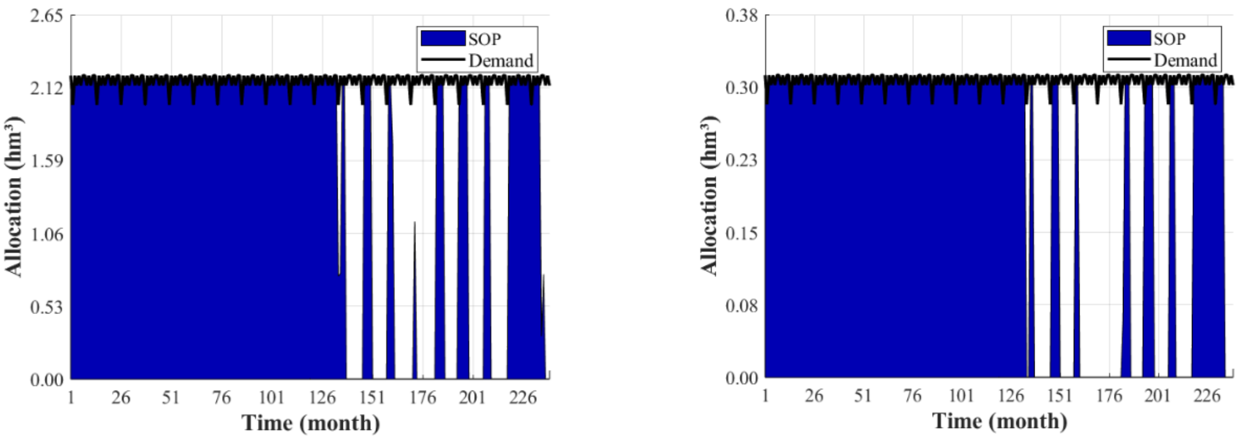
Figure 5 (A-F) shows the allocations for each user sector. As expected and seen in Table 6, the number of failures was significant for less-priority uses. The sectors with fewer difficulties were human supply (sanitation) and livestock, with 70 (29.2%) and 71 (29.6%) failures, respectively. The irrigation, aquaculture, and industry sectors had the highest frequency of problems in meeting demands, with 85 months with water deficits (35.4%) in a total of 240 months. Bezerra et al. (2022) observed similar outcomes when studying the operation of the *Curema-Mãe D'Água* water system from 2005 to 2020. With such results, we confirm that the reservoir is subject to severe water deficits. These water deficits emphasize the urgent need for effective measures to tackle water scarcity. Implementing water usage charges can play a crucial role in encouraging responsible practices such as pre-emptive rationing. This can help alleviate deficits and promote more sustainable water resource management.

Table 6 - Number of failures in meeting demands (2002-2021).

Uses	**Number of failures (months)**
Domestic	70
Livestock	71
Ecological flow	74
Irrigation	85
Aquaculture	85
Industry	85

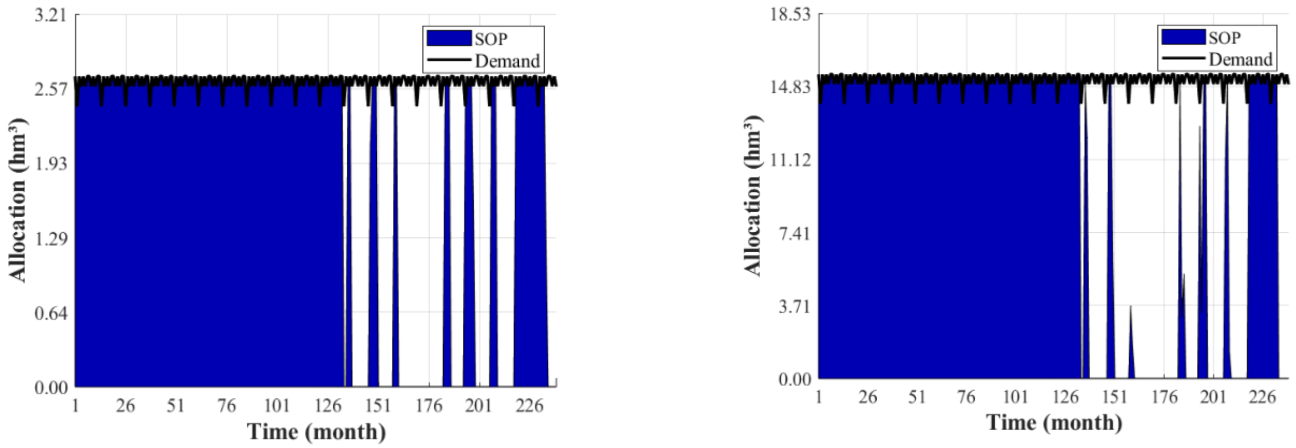
Source - Author *et al.*, 2023.

Figure 5 - Water allocation for each user sector

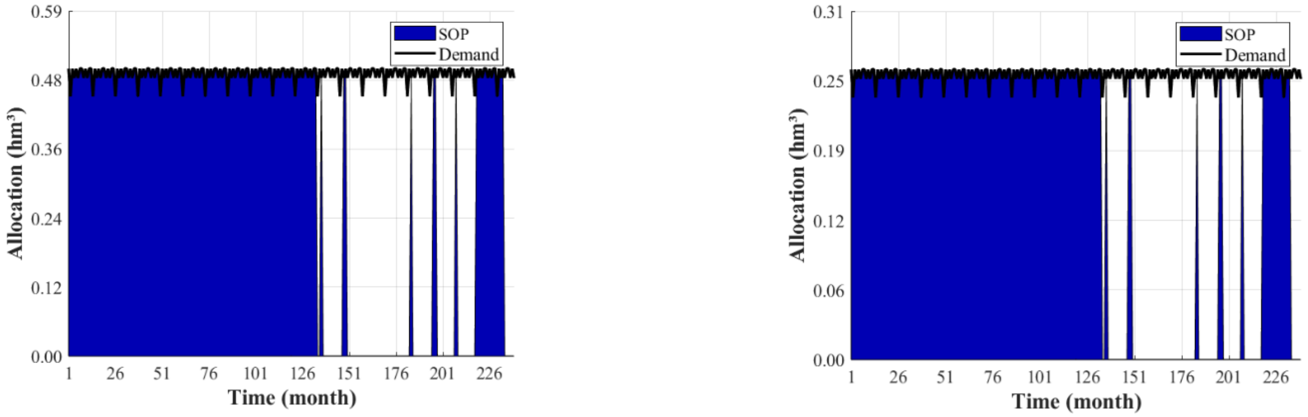


A) Water allocation for domestic (2002-2021).

B) Water allocation for livestock (2002-2021).


C) Water allocation for ecological flow (2002-2021).

D) Water allocation for irrigation (2002-2021).

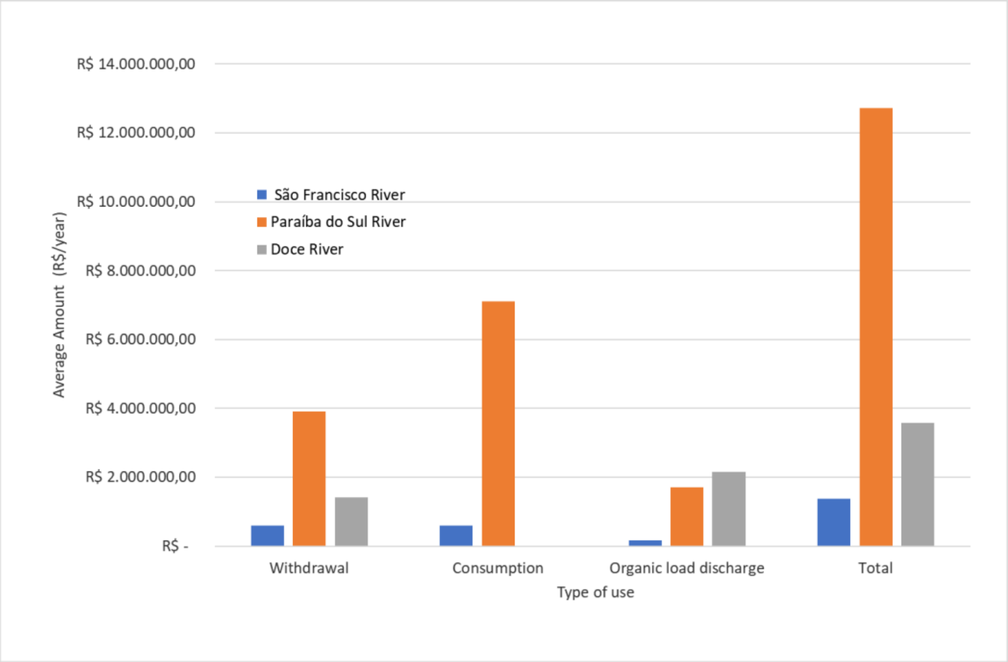

E) Water allocation for aquaculture (2002-2021).

F) – Water allocation for industry (2002-2021).

Source - Author et al., 2023.

Figure 6 shows the average collection values considering the components related to withdrawal, consumption and release of organic loads. Among the models, the one that provided the highest collection was that of the *Paraíba do Sul* River, R$ 12,711,071.69, followed by the *Doce* River and the *São Francisco* River, with R$ 3,577,895.45 and R$ 1,368,273.20, respectively. Another observation was that the *Paraíba do Sul* River model generated the higher values for withdrawal and consumption elements (R$ 3,905,312.91 and R$ 7,102,732.55). The *Doce* River model, on the other hand, provided the highest collection with the release of organic loads, summing R$ 2,156,229.37. It is worth noting that in the *Doce* River there is no charge for water consumption. Using the *São Francisco* River model, all the elements generated the lowest collections. The São Francisco River model uses the granted flows as a basis. In this way, regardless of the flow withdrawn, the tariff for use remains the same. As a positive factor, this method tries to induce the user who uses lower flows than the one granted to request the revision of the grant (VERA et al. 2017).

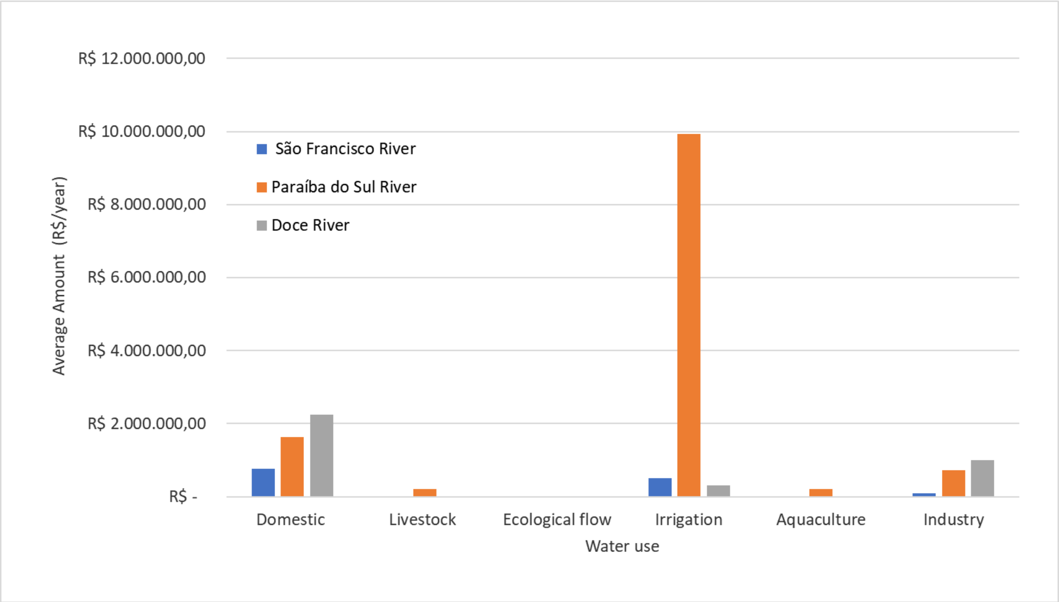
Figure 6 - Average annual collection by billing component for each model.



Source - Author *et al.*, 2023.

Figure 7 shows the average collection values considering each type of use for the three analyzed models. The highest collections occur for human supply (R$ 2,242,841.89 per year) and industry (R$ 990,336.76 per year) with the *Doce* River water basin model. When applying the *Paraíba do Sul* River model, the highest collection was for irrigation, with an annual value of R$ 9,922,943.70.

Figure 7 - Average annual collection by type of use.

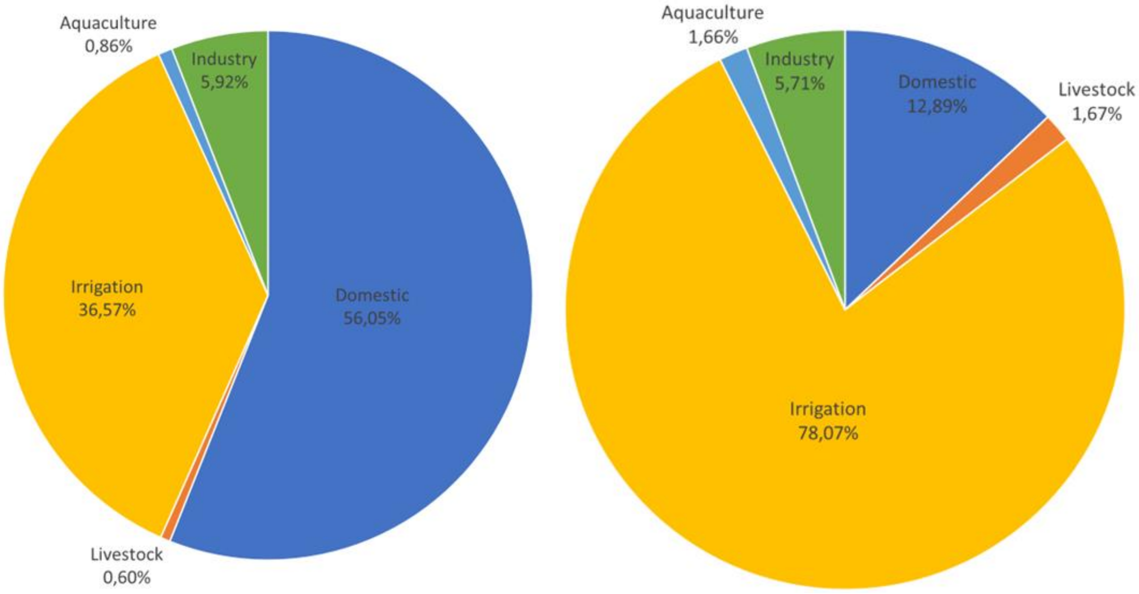


Source - Author *et al.*, 2023.

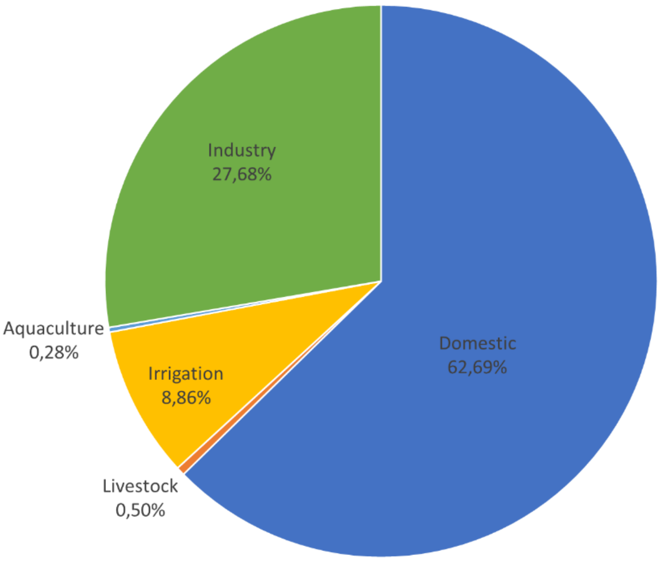
Figure 8 (A-C) shows the distribution of collection considering each type of use for the three analyzed models. The study showed that the sanitation sector is the greatest contributor when using the *São Francisco* and *Doce* river models (R$ 766,875.48 and R$ 2,242,841.89 per year, respectively). Irrigation is the greatest contributor when using the *Paraíba do Sul* model (R$ 9,922,943.70 per year). The increase in the irrigation sector when using the *Paraíba do Sul* model may be explained by the values of $K_{cap\ classe}$ and $K_{consumo}$ of 0,9 and 1, respectively, since the other models present lower values.

Figure 8 - Distribution of collections considering each type of use.

A) *São Francisco* River Basin B) *Paraíba do Sul* River Basin



C) *Doce* River Basin



Fonte - Author *et al.*, 2023.

Tables 7, 8, and 9 show the results of applying the collection models and present the amounts collected by sector in all years of the evaluation. According to the results, it is possible to collect annual averages of R$ 1,368,273.20, R$ 12,711,071.69, and R$ 3,577,895.45 by using the models of São Francisco, Paraíba do Sul, and Doce rivers, respectively. Considering the SOP model and the operational criteria of this application, the system would collapse in 2015 and 2016 for most uses, except for human supply (sanitation), implying the non-supply of water and the absence of any financial collection through the charge for collapsing uses.

Table 7 - Collection in thousands of reais per year using the collection model of the *São Francisco* River Basin Committee (2002-2021)

Collection (in thousands reais) – *São Francisco* River						
Year	**Domestic**	**Livestock**	**Irrigation**	**Aquaculture**	**Industry**	**Total**
2002	1,066.58	11.58	754.86	18.31	125.40	1,976.74
2003	1,066.58	11.58	754.86	18.31	125.40	1,976.74
2004	1,066.58	11.58	754.86	18.31	125.40	1,976.74
2005	1,066.58	11.58	754.86	18.31	125.40	1,976.74
2006	1,066.58	11.58	754.86	18.31	125.40	1,976.74
2007	1,066.58	11.58	754.86	18.31	125.40	1,976.74
2008	1,066.58	11.58	754.86	18.31	125.40	1,976.74
2009	1,066.58	11.58	754.86	18.31	125.40	1,976.74
2010	1,066.58	11.58	754.86	18.31	125.40	1,976.74
2011	1,066.58	11.58	754.86	18.31	125.40	1,976.74
2012	1,066.58	11.58	754.86	18.31	125.40	1,976.74
2013	331.15	2.92	176.86	3.06	20.96	534.96
2014	356.50	3.87	150.56	3.06	20.96	534.95
2015	249.04	1.94	22.01	0.00	0.00	272.98
2016	47.03	0.00	0.00	0.00	0.00	47.03
2017	356.50	3.07	96.96	1.51	10.31	468.34
2018	438.32	4.76	193.13	3.06	20.96	660.22
2019	268.84	2.92	114.09	1.51	10.31	397.66
2020	894.17	9.71	632.84	15.35	105.13	1,657.21
2021	663.64	6.73	318.16	7.58	51.88	1,047.99
Average	**766.88**	**8.17**	**500.41**	**11.83**	**81.00**	**1,368.27**

Source - Author *et al.*, 2023.

Table 8 - Collection in thousands of reais per year using the collection model of the *Paraíba do Sul* River Basin Committee (2002-2021)

Collection (in thousands of reais) – *Paraíba do Sul* River						
Year	**Domestic**	**Livestock**	**Irrigation**	**Aquaculture**	**Industry**	**Total**
2002	2,279.42	301.57	14,968.79	325.90	1,124.18	18,999.85
2003	2,279.42	301.57	14,968.79	325.90	1,124.18	18,999.85
2004	2,279.42	301.57	14,968.79	325.90	1,124.18	18,999.85
2005	2,279.42	301.57	14,968.79	325.90	1,124.18	18,999.85
2006	2,279.42	301.57	14,968.79	325.90	1,124.18	18,999.85
2007	2,279.42	301.57	14,968.79	325.90	1,124.18	18,999.85
2008	2,279.42	301.57	14,968.79	325.90	1,124.18	18,999.85
2009	2,279.42	301.57	14,968.79	325.90	1,124.18	18,999.85
2010	2,279.42	301.57	14,968.79	325.90	1,124.18	18,999.85
2011	2,279.42	301.57	14,968.79	325.90	1,124.18	18,999.85
2012	2,279.42	301.57	14,968.79	325.90	1,124.18	18,999.85
2013	707.72	76.01	3,507.19	54.46	187.88	4,533.26
2014	761.89	100.80	2,985.63	54.46	187.88	4,090.65
2015	532.23	50.40	436.40	0.00	0.00	1,019.02
2016	100.51	0.00	0.00	0.00	0.00	100.51
2017	761.89	80.00	1,922.69	26.79	92.40	2,883.77
2018	936.75	123.93	3,829.66	54.46	187.88	5,132.68
2019	574.54	76.01	2,262.40	26.79	92.40	3,032.14
2020	1,910.96	252.82	12,549.17	273.22	942.46	15,928.64
2021	1,418.30	175.16	6,309.08	134.83	465.08	8,502.43
Average	**1,638.92**	**2012.62**	**9,922.95**	**210.50**	**726.097**	**12,711.08**

Source - Author *et al.*, 2023.

Table 9 - Collection in thousands of reais per year using the *Doce* River Water Basin Committee 36model (2002-2021)

Collection (in thousands of reais) –*Doce* River						
Year	**Domestic**	**Livestock**	**Irrigation**	**Aquaculture**	**Industry**	**Total**
2002	3,119.36	25.22	478.23	15.34	1,533.29	5,171.44
2003	3,119.36	25.22	478.23	15.34	1,533.29	5,171.44
2004	3,119.36	25.22	478.23	15.34	1,533.29	5,171.44
2005	3,119.36	25.22	478.23	15.34	1,533.29	5,171.44
2006	3,119.36	25.22	478.23	15.34	1,533.29	5,171.44
2007	3,119.36	25.22	478.23	15.34	1,533.29	5,171.44
2008	3,119.36	25.22	478.23	15.34	1,533.29	5,171.44
2009	3,119.36	25.22	478.23	15.34	1,533.29	5,171.44
2010	3,119.36	25.22	478.23	15.34	1,533.29	5,171.44
2011	3,119.36	25.22	478.23	15.34	1,533.29	5,171.44
2012	3,119.36	25.22	478.23	15.34	1,533.29	5,171.44
2013	968.51	6.36	112.05	2.56	256.25	1,345.73
2014	1,042.63	8.43	95.39	2.56	256.25	1,405.26
2015	728.34	4.22	13.94	0.00	0.00	746.50
2016	137.54	0.00	0.00	0.00	0.00	137.54
2017	1,042.63	6.69	61.43	1.26	126.02	1,238.04
2018	1,281.93	10.37	122.35	2.56	256.25	1,673.46
2019	786.25	6.36	72.28	1.26	126.02	992.17
2020	2,615.13	21.15	400.93	12.86	1,285.44	4,335.51
2021	1,940.92	14.65	201.57	6.35	634.32	2,797.80
Average	**2,242.84**	**17.78**	**317.02**	**9.91**	**990.34**	**3,577.90**

Source - Author *et al.*, 2023.

According to the results, the *Paraíba do Sul* River model has the best collection potential for the studied water system. It is also clear that the annual collection by the *Paraíba do Sul* River model is almost ten times greater than the values found with the mechanism used in *São Francisco* River Basin, emphasizing the amounts generated by the irrigation use. The charges produced by the *Paraíba do Sul* River model in all sectors significantly exceeded the values provided by the *São Francisco* and *Doce* rivers' equations. The difference between the models was crucial to define differences between the amounts collected. It is also noteworthy to highlight the evolution the models under study have gone through over the years, becoming simpler and more practical. In addition, water quality became more relevant, especially in the charging model used in the *Doce* River Basin.

In the *São Francisco* River Basin, the equations use the concept of dilution flow - which relates the concentration of the pollutant and the allowed concentration - based on the classification class of the watercourse (CBHSF, 2017). Besides BOD, this allows accounting for different contaminants. The basins under study also seek to compensate users who prove, through measurements attested by the granting body, that the polluting load present in their effluent releases is lower than the polluting load in the water collected from the water body (CEIVAP, 2014; CBH-DOCE, 2018; CBHSF, 2017).

In March 2003, the *Paraíba do Sul* River Basin first implemented the charging instrument for the use of water resources through CEIVAP Deliberation Number 03/2001. In July 2010, the *São Francisco* River Basin Committee started charging for water use, although it was approved through Deliberation Number 40/2008 in 2008. The *Doce* River Basin Committee implemented the charge in 2011 through Deliberation Number 26/2011. The Unit Public Price in the *São Francisco* River Basin remained constant until 2017, impacting the collection, as "it represents an additional difficulty for achieving the investment targets and also for ensuring the financial sustainability of the agency" (LUCCHESE, 2019). Among the basins, the *Doce* River has the highest values for the Unit Public Price, which may be explained by the absence of values for water consumption (ALMEIDA, 2018). The *Paraíba do Sul* River Basin established progressive collection values between 2011 and 2015. The progressivity of the values is related to the achievement of disbursement targets by the Water Agency (ANA, 2019b). Furthermore, it is crucial to consider the pioneering attitude of the *Paraíba do Sul* River Basin, which started implementing unit prices in 2003.

In India, water is considered an economic good and subject to pricing (Parween et al., 2021). Analysis of the amounts charged for domestic and industrial use indicates that the values are reasonable. Nevertheless, for irrigation, water is considered by many a good without merit. Several governments provide financial support for non-meritorious goods or services. From such perspective, the models of the *São Francisco* and *Doce* rivers are similar, with large amounts for human supply (sanitation) and industry sectors. On the other hand, irrigation stood out (highest collection) in the comparison of uses when applying the *Paraíba do Sul* River model.

In Northwestern Ethiopia, Wassihun et al. (2022) noted that the low rate of water taxes, the lack of periodic review, and flaws in the current water charge mechanism limit the charging of irrigation water. Since irrigation water is not in the market, it is difficult to determine a cost using the principle of demand and supply. Although some agencies use public prices, the amounts charged still do not express the realistic value of water.

Examining global water pricing perspectives, regions face parallel challenges in valuing and pricing water resources. In India, water is increasingly seen as an economic good subject to pricing, yet irrigation faces undervaluation. In Northwestern Ethiopia, low water tax rates and valuation complexities hinder effective charging mechanisms. These findings stress the need to adapt water pricing models locally, ensuring sustainable resource management in regions confronting water scarcity challenges.

CONCLUSION

The water deficit from 2012 to 2017 emphasized the critical need for implementing a water usage charging model, which represents a significant step towards sustainable water resource management. Analysis of the system operation using the SOP model showed that the *Curema - Mãe D'Água* reservoir could not meet the required demands in 85 (35.4%) of the 240 studied months (2002-2021). Such conditions compromised water security and the collection potential, especially between 2012 and 2017.

Due to the different public prices and collection methodologies, the models used in the water basins of *Doce* and *Paraíba do Sul* rivers generated higher collections when compared to those obtained by the model used in the *São Francisco* River. Low public prices can make it impossible to reach investment targets and compromise the incentive for the rational use of water.

Despite the same structure for the charging mechanisms, considering withdrawal, consumption, and release of organic loads, the models presented gaps, such as the non-establishment of a unit price for water transposition and limitation for protecting water quality.

Although the investigated charging models are specific to local requirements, the coherence and advances seem to be a fair framework for other initiatives. Other than that, the need to reconcile public prices and collection mechanisms with local hydrological conditions and the reality of water users became evident.

In summary, the study not only identifies pressing issues but also lays the groundwork for innovative solutions. It is imperative to delve deeper into these findings, enhancing understanding and facilitating actionable steps towards more sustainable water management practices.

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