Water Supply

© 2024 The Authors Water Supply Vol 24 No 5, 1645 doi: 10.2166/ws.2024.098

Impact of efficiency on affordability: A study of the Brazilian new water loss goals

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ABSTRACT

Infrastructure service affordability has become a burgeoning concern over the past years due to the recent economic crisis and the growing role of tariffs in funding the services. Pressure on utilities to promote social assistance programs in addition to an efficient service has risen toward providing water as affordable as possible. This study shows the positive impact of efficient services on families' water affordability by analyzing the new Brazilian water loss goals and the potential effect of water loss reduction on total expenses reported in the Brazilian utilities' National Water and Sanitation Information System. The total service cost for water and sanitation (before and after the aforementioned goals) was then translated to average tariff per cubic meter and affordability ratios. The potential water volume saved in physical losses can reach up to 16.6% of the water consumed in the country, and although the impact on water affordability was timid, the positive results indicate utilities have an important role in assuring water and sanitation for all, and regulators must be involved toward taking a deep look at local conditions.

Key words: affordability, public policy, regulation, tariff, water access, water loss

HIGHLIGHTS

- Efficient utilities have an important role on water affordability.
- The new Brazilian water loss goals have potential positive outcomes for families' budget.
- Several Brazilian utilities may not achieve financial savings due to nonrevenue water programs costs.

1. INTRODUCTION

Water supply and sanitation (WSS) services are known for their complexity due to the social, health, environmental, economic, and political dimensions involved. The lack of services leads to economic losses regarding their impact on both the environment and human lives. Aware of that, the United Nations has recognized access to WSS as a human right and included it in more than one of the sustainable development goals (SDG) to be achieved by 2030 (WHO & UNICEF 2021a). Among the nations that still lack WSS services, Brazil's water supply coverage is 84.2% of the population and sewage systems coverage only 55.8% (BRASIL 2022). Moreover, high water losses, intermittent services, and high water and energy consumption lead to inefficient services, as shown in Figure 1 (BRASIL 2022).

Brazilian inequality among macro-regions is also reflected in WSS access, with water supply for 91.5% of people in the Southeast against 60% in the Northern region. Sanitation coverage varies between 14% in the Northern and 81.7% in the Southeast region (BRASIL 2022). In Brazil, municipalities are responsible for WSS services, except in Metropolitan Areas, which have their own governance mechanism. WSS provision can be direct through local entities or delegated through the private sector or to state-owned companies (Narzetti & Marques 2021). State-owned WSS companies were created in the 1970s to enable economies of scale and provide WSS services to more than 70% of the total population. Nevertheless, there are approximately 1,303 municipal or community water providers and 3,310 wastewater ones, thus posing another challenge to universal access (BRASIL 2022).

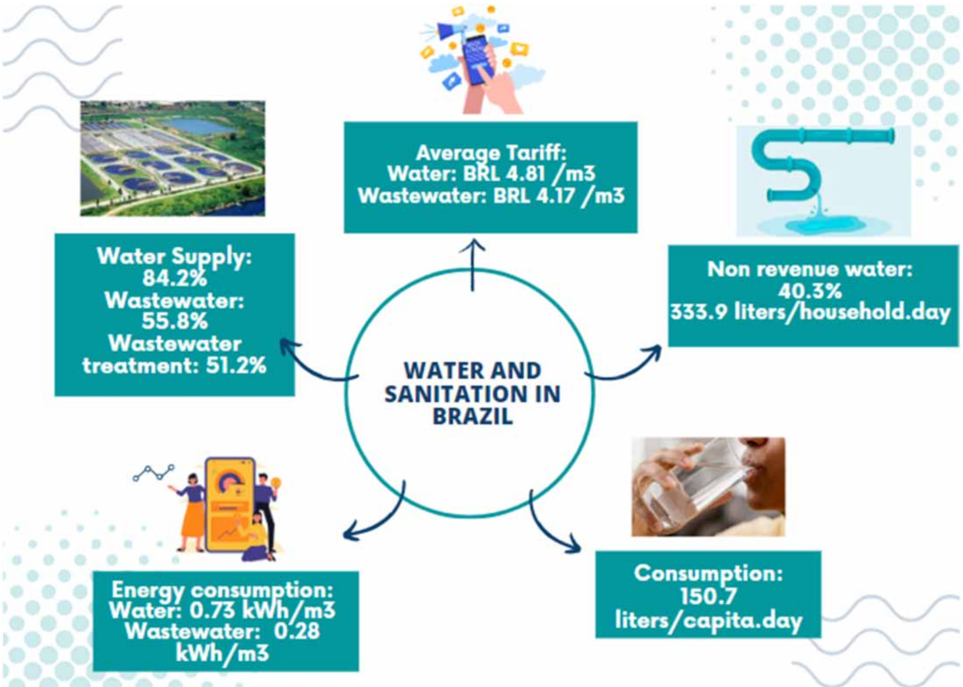

Figure 1 | Brazilian WSS sector main numbers. *Source*: BRASIL 2022.

Past Brazilian governments struggled to meet SDG over the last decades, with lower results than expected. In 2020, the federal government conducted an extensive sector reform toward accelerating WSS universalization through increasing private sector participation – law No. 14.026 of 15 July 2020 (known as the new WSS law). Among several changes, the most important ones were promotion of private sector participation through the adoption of the neutrality principle between state-owned and private operators, WSS regulation improvement through the standardization of subnational water regulation, granting of WSS services in regional blocks of cities, increasing their financial attractiveness, and promotion of efficiency toward specific targets, including universal access by 2033 (Narzetti & Marques 2022). The focus on efficiency has resulted from social and political pressure regarding the current low-quality services, even after the creation of state-owned WSS companies.

As discussed in previous studies, efficient WSS services reflect on the environment, due to a decrease in river pollution and water extraction, and also on climate change and health, considering the consumption of energy and the reduction of waterborne diseases (Kingdom *et al.* 2006; Wyatt & Alshafey 2012; European Union 2015; Cetrulo *et al.* 2019; Molinos-Senante *et al.* 2020; Pereira & Marques 2022).

The current population growth and increase in droughts and flood events have demanded efficient WSS services for utilities' long-term survival, including eficient level of NRW. Conservative estimates considering USD 0.31 per cubic meter indicate the cost/value of water lost amounts to USD 39 billion annually (Liemberger & Wyatt 2019). The same study claimed if the world's nonrevenue water (NRW) were reduced by one-third, the savings would supply 800 million people, considering a per capita consumption of 150 L per day. Besides regular operational cost savings, water losses involve negative externalities, and previous studies have suggested the calculation of the implicit value of water – called shadow price (Molinos-Senante *et al.* 2016, 2019; Brea-Solis *et al.* 2017). A study comparing the shadow prices of water leakage with tariffs of 23 Chilean water companies over 2007–2015 showed that most utilities have economic incentives to reduce water losses considering the limit of 15% established by the regulator in tariff setting. Since they still have not achieved such reductions, the authors recommend that the regulatory authority introduce direct penalties to incentivize the reduction of water loss indicators (Molinos-Senante *et al.* 2019). However, reducing NRW is a complex task and requires continuous actions. NRW has three components, namely, physical losses, apparent losses (theft of water and customer meter under registration), and unbilled authorized consumption (European Union 2015). Toward simplification, several analyses have considered unbilled consumption and apparent losses as commercial losses (Wyatt 2010).

Many regulators worldwide have established water loss targets considering political, economic, social, or environmental factors (EA 2012; Water UK 2016). Although extremely sensitive to social and political pressure, apparent loss reduction can potentially recover revenue faster and simpler than physical loss projects. Improvements in bill systems and meter reading along with social actions for reducing unauthorized consumption can increase revenue for utilities, especially in low- and middle-income countries. Leakage reduction programs, on the other hand, can be very capital intense, but with reductions in operating costs such as energy, chemicals, sludge disposal, abstraction charges, water purchase, and also in future capital expenses (e.g., new water catchment, water transmission and treatment plants, and storage tanks) (European Union 2015). It also depends on network configuration and varies in function of the service area, including density, topography, and management skills (Drusiani *et al.* 2013; Molinos-Senante *et al.* 2019).

Actions for reducing NRW should take into account the payback period and the benefit–cost ratio, because local environmental and socioeconomic conditions might vary significantly among utilities (Wyatt 2010). Several methodologies have been suggested worldwide to evaluate the value of water as precisely as possible and establish the economic levels of NRW (EA 2012; European Union 2015; Wyatt *et al.* 2021). Besides the cost of measures for NRW reductions (especially physical losses) and the savings of operational expenses, regulators (EA 2012) and international organizations have started to promote the inclusion of postponing capital expenditure, called long-run economic level of leakage (European Union 2015). The inclusion of environmental and resource costs, considering water scarcity and ecosystem needs, called sustainable economic level of leakage, is also suggested. Although not mandatory, the European Water Framework Directive 2000/60/EC has established that the total cost of water should be applied in a tariff setting, which includes operating costs, capital expenditures, return of capital, and resource and environmental costs (Drusiani *et al.* 2013).

Considering the new Brazilian WSS law and the importance of efficiency in the water sector, in 2021, the Ministry of Regional Development enacted water loss targets for the next 10 years. Ordinance No. 490/2021 established access to the federal budget will be conditioned on lowering the two main water loss indicators, namely, percentage of input system volume and liters per connection per day. Although simplistic, since it does not consider local costs for improvements or any economic level of loss measurement, the Brazilian Ministry started to officially demand for efficient WSS services. A study conducted by the Brazilian Association of Sanitary Engineering estimated that a 38% reduction in the water loss indicator might have led to a total net benefit of BRL 14.97 billion (USD 3.03 billion) in 17 years, from 2009 to 2025 (ABES 2013). Recent research, using data from SNIS 2021, analyzed the benefits of water loss reduction in three scenarios – 15, 25, and 35% as final targets (Instituto Trata Brasil 2023). According to the authors, considering the cost of implementation as 50% of the monetary benefit, the potential net benefit might achieve BRL 27.4 billion (USD 5.55 billion) from 2021 to 2034.

SDG 6 established that access to WSS should be guaranteed at an affordable price. Despite the affordable level being currently a nonconsensus discussion between academics and practitioners, the basic idea is the payment for a specific service should not jeopardize the payment for other essential needs (Andres *et al.* 2020; WHO & UNICEF 2021b). Methodologies for analyses of water affordability have varied among studies and their adoption relies mainly on both objectives of the analysis and data availability (Martins *et al.* 2016; Andres *et al.* 2020; WHO & UNICEF 2021b; Fagundes *et al.* 2023). Nevertheless, analyses surround the impact of WSS bills (or expenditures) on families' income.

Although heavily subsidized (Andres *et al.* 2019), the WSS sector may considerably impact families' ability to pay for other services, especially if the cost recovery principle is applied. Through efficiency, cost savings might be reflected in reduced tariffs, leading to more affordable WSS services. Affordable WSS service is a shared responsibility that should be addressed mainly by governments; however, WSS utilities have a crucial role as efficient providers, assuring every citizen perceives high-quality service at the lowest possible cost. Reductions in water losses contribute to both environmental conditions and the maintenance of more affordable services, decreasing operational costs and postponing investments in water production augmentation.

This article addresses the impacts of efficient WSS services on water affordability. It analyzes the potential effect of Brazilian new water loss goals (Ordinance No. 490/2021) on families' budgets, including most vulnerable households, and highlights water loss target setting should take into account the local conditions and the role of water regulators. It is organized as follows: Section 2 presents the methodology adopted. Section 3 discusses the main results and limitations of the study. Finally, Section 4 provides the concluding remarks and suggestions for further research.

2. METHODS

2.1. Sample

Brazil monitors its WSS services performance, including solid waste and urban drainage, through the National Sanitation Information System (SNIS in Portuguese acronym). To be able to access the federal budget, utilities must provide the Ministry of Regional Development with annual information; the Ministry then publishes the country's current scenario and evolution some months later. Data are public and available online. Although largely adopted by providers, SNIS is a self-declared platform, which brings in challenges related to accuracy and consistency. The latest available SNIS publication, from 2022 with data from 2021, was used in this study.

The initial sample was 5,979 utilities, of which exclusive wastewater providers, i.e., 552 utilities, were eliminated since this study analyzes the impact of water loss reduction. The Brazilian Ordinance sets targets for the two leading water loss indicators, the % of the system input volume (SIV), indicator IN049 from SNIS, and water loss in liters per connection per day (lcd), indicator IN051 from SNIS. Water loss performance indicators display different characteristics, which make them suitable for some purposes, but not all. Several international standards organizations, such as the International Water Association Performance Indicators Group, and some regulators have highlighted the failure of using the percentage of SIV to express leakage and set targets (Wyatt 2010; European Union 2015; AWWA 2019; IWA 2022). Water losses defined as % of SIV distort the perception of performance due to the influence of changes on consumption. Therefore, this study analyzed the impacts of Ordinance no. 490/2021 only on indicator IN051, according to Equation (1):

$$\mathrm{IN051}\left(\frac{\mathrm{Liters}}{\mathrm{Connection.day}}\right)=\frac{1{,}000{,}000}{365}\times\frac{\mathrm{AG006}+\mathrm{AG018}-\mathrm{AG010}-\mathrm{AG024}}{\mathrm{AG002}} \tag{1}$$

where AG002 is the number of active connections, AG006 is the water produced (m^3/year), AG010 is the water consumed (m^3/year), AG018 is the water imported (m^3/year), and AG024 is the water for utility's own services (m^3/year).

Considering the required information of Equation (1), samples with zero or null values for information AG006, AG010, and IN051 were deleted, leading to 5,274 ones. Utilities with water produced equals zero, but any volume of imported water remained in the sample. Some outliers were observed for IN051 (e.g., zero or 28,000), and toward decreasing their influence, the 2% bottom and top ones were eliminated, leading to 5,063 samples.

Interestingly, 1,533 samples (representing 14.8% of the Brazilian population) reported 0% macro measurement, i.e., providers of those cities had no measurement equipment for input volume, thus probably relying on estimates. The other 253 samples reported 0% meter reading. As observed in Equation (1), both data directly influence IN051 calculation. In some cases, utilities are bulk water buyers (e.g., the Metropolitan Region of Maceió, in Alagoas state, Mauá, and Santo André, in São Paulo) and, therefore, were not deleted, but analyzed with caution. Finally, 180 samples that report no average tariff or water consumed per household were deleted, since those data are required for water affordability analyses, leading to a final number of 4,883 samples/cities.

Some households in 1,241 cities suffer from intermittent water supply, negatively influencing physical water losses. Although indicator IN051 is expressed in liters per connection per day, it does not take into account the influence of intermittent services. Even though SNIS has helpful information on the subject (e.g., number of water supply interruptions per year and duration of disruption in the year), the number of households hit by interruptions includes repetition. If a household suffered 20 times from intermittent services in 1 year, the number of 'households' informed would be 20 and not one. Consequently, the indicator could not be adapted for those samples.

2.2. Cost saving calculation

According to the Federal Ordinance, the water losses of utilities (indicators IN049 and IN051) must be equal to or lower than the percentage expressed in Figure 2 of the previous year national average.

Therefore, the value of the biannual goals will vary over the years, since the national average is expected to decrease. Toward simplifying the exercise, the last available national average for indicator IN051 (333.9 L per connection per day in 2021) was used as T_0 for the calculation of the goals until 2034, according to the percentage from Figure 2, leading to the values shown in Figure 3.

Figure 2 | Water loss targets of ordinance No. 490/2021.

Figure 3 | Targets for indicator IN051.

Considering the available IN051 for 2021, the initial one, the potential annual water savings in cubic meters were calculated from 2024 to 2034. A lack of local detailed water balance for all 4,883 samples and toward a separation between NRW components and impact, apparent losses were considered to be 40% and physical losses 60%, based on data from previous studies for low- and middle-income countries (Kingdom *et al.* 2006; Liemberger & Wyatt 2019), which may differ largely among WSS providers.

Aiming at the calculation of the water loss reduction impact, the potential reduction in total service expenses (TSE, indicator FN017 in SNIS) was assumed to directly influence the average tariff, which might not be accurate, since Brazil has subnational water regulators applying different tariff-setting methodologies, not available in SNIS. TSE expresses all the costs of the utility for providing WSS services. The analysis was divided into two parts for the calculation of the potential TSE reduction from apparent and physical losses.

a. Potential revenue from apparent losses reduction (RAL):

$$\text{RAL}\left(\frac{\text{BRL}}{\text{Year}}\right) = ((T_i - \text{T}_0)\ \times\ 0.365\ \times\ 40\%\ \times\ \text{AG002}\ \times\ \text{IN004}) - \text{Meter cost} \tag{2}$$

where T_i is the IN051 target of year i, as displayed in Figure 3 (lcd), T_0 is the initial IN051 (lcd), AG002 is the number of active connections, from SNIS, IN004 is the average tariff (BRL/ m^3), from SNIS, and meter cost is the average cost for water meter replacement program per city (BRL/year) from (Wyatt *et al.* 2021).

The study conducted for Brazilian municipalities (Wyatt *et al.* 2021) in 2019 is the most specific estimate found regarding water loss projects. The cost for water meter replacement programs per city was updated to December 2021, considering Brazilian cumulative inflation and the month of SNIS data used in this study.

b. Potential cost saving from physical losses reduction (CPL):

Since most service expenses rely on energy, chemicals and, in some cases, imported bulk or treated water, these three items were considered in the calculation of production cost (and its potential savings). Utilities provide the following expenses per year to SNIS: energy (indicator FN013), chemicals (indicator FN011), and imported water (indicator FN020). With the produced volume per year (AG006), the cost per cubic meter for each item was calculated. Regarding energy and chemicals expenses, for the cities with zero water produced, but with the volume of imported water, the latter one was used, which may be the case of treated or bulk water buyers, in which they remain as distributors and still have energy and chemicals costs. Although energy expenses include those with wastewater, the average and median of the percentage of water volume in the total volume (water + wastewater) were 94.5 and 100%, respectively. The cost per cubic meter of the three main components led to the item's yearly potential cost savings.

$$\text{Item unit cost}\left(\frac{\text{BRL}}{\text{m}^3}\right) = \frac{\text{Item expenses}\left(\frac{\text{BRL}}{\text{Year}}\right)}{\text{Produced or imported water}\left(\frac{\text{m}^3}{\text{Year}}\right)} \tag{3}$$

where item expenses are SNIS indicator FN013 for energy, FN011 for chemicals, and FN020 for imported water, produced water is SNIS indicator AG006, and imported water is SNIS indicator AG018.

$$\text{Item potential savings}\left(\frac{\text{BRL}}{\text{Year}}\right) = (T_i - T_0) \times 0.365 \times 60\% \times \text{Unit cost} \times \text{AG002} \tag{4}$$

where T_i is the IN051 target of year i (lcd), T_0 is the initial IN051 (lcd), Unit cost is the cost for energy, chemicals, or imported water calculated by Equation (3), and AG002 is the number of active connections from SNIS.

Costs of water reduction project rely on the local environment and the current technical level of the utilities. Our 4,883 samples have cities from all over Brazil, which hamper any estimates for such a cost. Nevertheless, the forecast per city from the study by Wyatt *et al.* (2021) was used, as did in potential savings from apparent loss reduction, updated considering Brazilian cumulative inflation to December 2021. Equation (5) is used to calculate the total potential savings.

$$\text{Savings from physical loss reduction (SPLR)}\left(\frac{\text{BRL}}{\text{Year}}\right) = \sum \text{Item potential savings} - \text{WLRP} \quad (5)$$

where WLRP is the average cost for water loss reduction programs for each city (BRL/year) from (Wyatt *et al.* 2021).

Toward the insertion of an idea of postponement costs from water loss reduction, the avoided cost of augmentation (ACA) was computed according to Equation (6). The cost of expansion was an update of a previous study from the Brazilian Ministry of Development (Cavaleiro *et al.* 2019) (BRL 0.32/m^3 in October 2016 and BRL 0.41/m^3 for December 2021).

$$\text{ACA}\left(\frac{\text{BRL}}{\text{Year}}\right) = (T_i - T_0) \times 0.365 \times 60\% \times \text{AG002} \times 0.41\left(\frac{\text{BRL}}{\text{m}^3}\right) \quad (6)$$

where T_i is the IN051 target of year i (lcd), T_0 is the initial IN051 (lcd), and AG002 is the number of active connections from SNIS.

The potential annual economy of TSE was calculated with the sum of the ACA, the potential savings from physical water loss, and the revenue from apparent loss reduction, as displayed in Equation (7), and provided the final reduction in average tariff, used in the calculation of affordability ratios (ARs).

$$\text{TSE potential savings (\%)} = \frac{\text{SPLR} + \text{RAL} + \text{ACA}\left(\frac{\text{BRL}}{\text{Year}}\right)}{\text{TSE}\left(\frac{\text{BRL}}{\text{Year}}\right)} \quad (7)$$

where SPLR is the savings from physical water loss reduction, RAL is the revenue from apparent loss reduction, and ACA is the avoided cost of augmentation.

The potential TSE savings were not calculated for samples that meet the targets established by ordinance. However, all samples with potential cubic meter savings were included in the analysis, even if the cost of water loss reduction actions was greater than the financial benefits. The estimates for programs, for both apparent and physical water reductions, used in this study correspond to the values found for the corresponding economic level of water loss (Wyatt *et al.* 2021), i.e., for some cities, those costs are greater than it will be to meet the ordinance targets since the range of economic water level found by Wyatt *et al.* 2021 was 40–110 L per connection per day.

2.3. Affordability analysis

The potential economy of TSE enabled the calculation of the impact on average tariff and then on water affordability. Several methodologies have been suggested to calculate affordability issues (Fagundes *et al.* 2023), such as expenditure ratios and poverty prevalence. However, since Brazilian income data have been recently released and SNIS has the average tariff per city, the burden of WSS bill on families' income was used as the affordability indicator in this study. The initial average tariff is from 2021 SNIS data (indicator IN004), and from 2024 to 2034, the potential savings reported in Section 2.2 were applied to this initial tariff. Three ARs were calculated for the analysis of the impact on families with average wages and in vulnerable conditions, receiving or not discount from social tariffs, a common type of WSS subsidy in Brazil. The ARs used the average wage per state, the most recent income data available. For poorer households, the AR considered families' income as ½ minimum wage per capita, since this is the poverty line for social tariffs in energy and communication sectors and applied by many water regulators. Although the discount for such a tariff varies among utilities and regulators, it was considered to be 50%. All ARs are expressed in Equations (8)–(10).

$$\text{AR1}(\%) = 100 \times \frac{\text{IN004} \times \text{IN017}}{\frac{\text{Hab}}{\text{HH}} \times \text{Occupancy Rate} \times \text{Average Wage}} \quad (8)$$

where IN004 is the average tariff (BRL/m^3), IN017 is the average water consumed per household (m^3/HH.month), Hab/HH is the number of inhabitants per household for each state (Source: IBGE, 2023, available at <https://www.ibge.gov.br/estatisticas/'sociais/trabalho/ 22827-censo-demografico-2022.html?edicao=37225&t=resultados>), the occupancy rate is the proportion of the population with a paid occupation, with 45.56% national average (Source: PNADC, 2023, available at <https://sidra.ibge.gov.br/home/pnadcm>), and average wage is the average monthly wage per person older than 14, per state (Source: PNADC, 2023, available at <https://sidra.ibge.gov.br/home/pnadcm>).

$$AR2(\%) = 100 \times \frac{IN004 \times IN017}{\frac{Hab}{HH} \times \frac{1}{2}\text{Minimum Wage}} \tag{9}$$

where IN004 is the average tariff (BRL/m^3), IN017 is the average water consumed per household (m^3/HH.month), Hab/HH is the number of inhabitants per household for each state (Source: IBGE, 2023, available at <https://www.ibge.gov.br/estatisticas/sociais/trabalho/ 22827-censo-demografico-2022.html?edicao=37225&t=resultados>), and the Brazilian Minimum Wage was BRL 1320,00 in October 2023.

$$AR3(\%) = 100 \times \frac{\frac{IN004}{2} \times IN017}{\frac{Hab}{HH} \times \frac{1}{2}\text{Minimum Wage}} \tag{10}$$

where IN004/2 is the average tariff with 50% discount from social tariff (BRL/ m^3), IN017 is the average water consumed per household (m^3/HH.month), Hab/HH is the number of inhabitants per household for each state (Source: IBGE, 2023, available at <https://www.ibge.gov.br/estatisticas/sociais/trabalho/22827-censo-demografico-2022.html? edicao=37225&t=resultados>), and the Brazilian Minimum Wage was BRL 1320,00 in October 2023.

Since the average wage per state considers just people with a paid occupation older than 14, the family income was calculated by multiplying the average salary by the proportion of the Brazilian population with a paid occupation and by the number of people per household in each state. To find families' total income when the salary was ½ minimum wage per capita, it was multiplied by the number of people per household. The reason for calculating two different ARs for vulnerable families (with and without social tariff) is that, unfortunately, even eligible, according to the Brazilian Association of Regulatory Agencies (Galvão Júnior *et al.* 2018), many vulnerable families have no access to the discount due to lack of information and additional restricted local rules. The ARs were calculated for every different target of ordinance, considering the average tariff with the discount from TSE savings and the average consumption per household from SNIS 2022 (indicator IN017).

3. RESULTS AND DISCUSSION

As addressed elsewhere, SNIS is the national self-declared platform with plenty of information on water supply, sanitation, urban drainage, and solid waste services. Since the allocation of federal public resources is conditioned to data provision, 5,335 cities (95.8% of the total, representing 98.6% of the total population) reported their information to the system in 2021 (BRASIL 2022). Nevertheless, according to the methodology in Section 2, the analysis was conducted with 4,883 samples/cities.

After the potential annual water savings in cubic meters were run for each city using the goals for IN051 from ordinance No. 490/2021 and $IN051_{year\ 2021}$ as the initial one, many samples had zero potential water savings, since their $IN051_{year\ 2021}$ was already lower than the targets, as shown in Table 1.

According to the table, almost 80% of the samples, corresponding to 55.9% of the population in Brazil, had already met the goal of 95% national average value of IN051. The first conclusion was that the ordinance is too soft, or most providers are close to efficiency. Nevertheless, SNIS also provides information on the percentage of input volume measured. In this study, 1,643 out of the 4,883 (33.6%) reported less than 50% of macro measurement and 1,400 (28.7%) reported zero, meaning water loss indicator IN051 for those cases might be incorrect, since the utilities do not have 100% of their volume measured, highlighting the accuracy issue of SNIS. In fact, only 2,857 (58.5%) have more than 90% of the input volume measured. The federal government is aware of this and has started implementing the '*ACERTAR*' project, according to which water regulators are responsible for auditing the leading SNIS indicators, including the ones of water losses. Nevertheless, savings are still

Table 1 | Samples with no potential for water savings

	Year 2024	Years 2025/2026	Years 2027/2028	Years 2029/2030	Years 2031/2032	Year 2033	Year 2034
Proportion of samples with no potential for water savings (%)	79.7	77.6	76.1	74.6	72.5	69.4	66.8
Proportion of population served by utilities with no potential for water savings (%)	55.9	52.7	49.6	46.8	38.9	36.3	33.9

valuable when considering the whole country. From Equation (2), the potential revenue from apparent losses reduction and its proportion on TSE for the whole country is observed in Table 2.

The analysis shows some limitations. The WSS sector is recognized as highly subsidized, and more than 70% of the Brazilian population is provided by state-owned companies, which obtain funds from the federal budget, mainly for capital expenses. Several utilities have neither fully applied the full cost recovery principle nor the universalization. With the new WSS Law, providers must meet coverage goals until 2033, which will naturally contribute to raising the TSE. Part of Equation (4) calculates the total potential volume saved, expressed in Table 3 as a percentage of produced and consumed water.

The potential for savings in cubic meters reaches 12.7% of the water produced and 16.6% of consumed water, leading to several potential positive aspects, such as reduced water abstraction expenses, and higher water availability for ecosystems. Leakage experts are aware that total elimination of real losses is impossible, and there is always a level of leakage to be tolerated in any system. Unavoidable real losses, as called by some authors (Wyatt 2010; European Union 2015), were not considered in this study due to our sample's lack of pressure information.

Measurements of affordable WSS services have been discussed worldwide, since the ability to pay for every essential need is highly dependent on local socioeconomic conditions. Nevertheless, some international organizations have used thresholds to analyze WASH access. As in previous studies (Martins *et al.* 2016; Andres *et al.* 2020; Fagundes *et al.* 2023), 3 and 5% thresholds were applied in this research, and the AR results are displayed in Tables 4–6.

According to the tables, average WSS bills are already affordable in 2023 for most Brazilian cities if a 3% threshold is considered, except for vulnerable families with no access to social tariffs (Table 5). A slight increase in the proportion of cities with AR between 3% and 5% was observed with the implementation of the federal goals. Despite obvious potential savings (Tables 2 and 3), some cities would spend more than the potential financial savings to implement water loss reduction projects and meet the national targets. This may be due to their low water tariff, absence of economies of scale, or, as addressed

Table 2 | Potential revenue and savings from reductions in apparent water losses

	Year 2024	Years 2025/2026	Years 2027/2028	Years 2029/2030	Years 2031/2032	Year 2033	Year 2034
Potential revenue from apparent loss reduction (1,000 USD/year)[a]	531,998.91	570,467.15	613,411.86	768,065.03	828,181.53	887,882.46	954,067.20
Proportion of total service expenses (%)	3.9	4.2	4.5	5.7	6.1	6.6	7.1

[a]The exchange rate used dates from 09/11/2023. 1 USD = 4.94 BRL.

Table 3 | Potential savings from physical water losses in Brazil

	Year 2024	Years 2025/2026	Years 2027/2028	Years 2029/2030	Years 2031/2032	Year 2033	Year 2034
Physical losses savings (1,000 m^3/year)	1,064,254	1,141,872	1,225,772	1,315,866	1,418,216	1,530,727	1,648,240
Proportion of produced water (%)	8.2	8.8	9.5	10.2	10.9	11.8	12.7
Proportion of consumed water (%)	10.7	11.5	12.4	13.3	14.3	15.4	16.6

Table 4 | Affordability ratio for average wage (cities)

Affordability ratio 1	Year 2023	Year 2024	Years 2025/2026	Years 2027/2028	Years 2029/2030	Years 2031/2032	Year 2033	Year 2034
Proportion of cities with AR 0–3%	99.32%	99.16%	99.12%	99.08%	98.20%	98.12%	97.95%	97.85%
Proportion of cities with AR 3–5%	0.61%	0.72%	0.76%	0.80%	1.27%	1.33%	1.49%	1.54%
Proportion of cities with AR >5%	0.06%	0.12%	0.12%	0.12%	0.53%	0.55%	0.55%	0.61%

Table 5 | Affordability ratio for poorer households (cities)

Affordability ratio 2	Year 2023	Year 2024	Years 2025/2026	Years 2027/2028	Years 2029/2030	Years 2031/2032	Year 2033	Year 2034
Proportion of cities with AR 0–3%	63.08%	63.63%	63.44%	63.65%	62.22%	62.07%	61.77%	61.81%
Proportion of cities with AR 3–5%	31.97%	31.46%	31.68%	31.44%	32.01%	32.25%	32.38%	32.32%
Proportion of cities with AR >5%	4.96%	4.92%	4.87%	4.92%	5.78%	5.67%	5.86%	5.88%

Table 6 | Affordability ratio for poorer households with social tariff (cities)

Affordability ratio 3	Year 2023	Year 2024	Years 2025/2026	Years 2027/2028	Years 2029/2030	Years 2031/2032	Year 2033	Year 2034
Proportion of cities with AR 0–3%	99.26%	99.08%	99.06%	99.06%	98.46%	98.46%	98.26%	98.14%
Proportion of cities with AR 3–5%	0.70%	0.82%	0.86%	0.86%	1.06%	1.06%	1.29%	1.33%
Proportion of cities with AR >5%	0.04%	0.10%	0.08%	0.08%	0.47%	0.47%	0.45%	0.53%

elsewhere, imprecise water loss indicators reported to the SNIS platform. According to Tables 7–9, in terms of population served by utilities (indicator AG001 in SNIS), the situation over the years is somewhat better than the results considering the number of cities, which means that bigger cities may benefit from the ordinance targets, increasing their positive impact on water affordability.

Comparing the AR in 2023 with those of years 2024–2034, Tables 10 and 11 show that although the number of cities with an increase in the three affordability indicators is higher than the ones that experienced a decrease, in terms of population, more people improved their ability to pay for WSS services – almost 70 million in 2034. The results raise concerns about

Table 7 | Affordability ratio for average wage (population)

Affordability ratio 1	Year 2023	Year 2024	Years 2025/2026	Years 2027/2028	Years 2029/2030	Years 2031/2032	Year 2033	Year 2034
Proportion of population with AR 0–3%	99.65%	99.49%	99.62%	99.58%	99.54%	99.47%	99.42%	99.45%
Proportion of population with AR 3–5%	0.29%	0.44%	0.31%	0.35%	0.35%	0.41%	0.48%	0.44%
Proportion of population with AR >5%	0.06%	0.07%	0.07%	0.07%	0.11%	0.11%	0.10%	0.11%

Table 8 | Affordability ratio for poorer households (population)

Affordability ratio 2	Year 2023	Year 2024	Years 2025/2026	Years 2027/2028	Years 2029/2030	Years 2031/2032	Year 2033	Year 2034
Proportion of population with AR 0–3%	51.18%	51.78%	51.84%	51.85%	51.98%	52.35%	52.66%	53.03%
Proportion of population with AR 3–5%	45.71%	45.21%	45.26%	45.25%	45.28%	45.08%	44.76%	44.45%
Proportion of population with AR >5%	3.11%	3.01%	2.90%	2.90%	2.74%	2.57%	2.58%	2.52%

Table 9 | Affordability ratio for poorer households with social tariff (population)

Affordability ratio 3	Year 2023	Year 2024	Years 2025/2026	Years 2027/2028	Years 2029/2030	Years 2031/2032	Year 2033	Year 2034
Proportion of population with AR 0–3%	99.27%	98.83%	98.85%	98.84%	98.93%	98.93%	98.89%	98.90%
Proportion of population with AR 3–5%	0.67%	1.10%	1.08%	1.10%	0.98%	0.97%	1.06%	1.04%
Proportion of population with AR >5%	0.06%	0.06%	0.06%	0.06%	0.10%	0.09%	0.05%	0.06%

Table 10 | Cities affected by variation in affordability ratio

Variation in AR	Year 2024	Years 2025/2026	Years 2027/2028	Years 2029/2030	Years 2031/2032	Year 2033	Year 2034
Decrease of AR	510	556	606	573	618	667	720
Increase of AR	481	540	559	669	726	825	900
No change	3892	3787	3718	3641	3539	3391	3263

Table 11 | Population affected by variation in affordability ratio

Variation in AR	Year 2024	Years 2025/2026	Years 2027/2028	Years 2029/2030	Years 2031/2032	Year 2033	Year 2034
Decrease of AR	38,262,341	40,750,710	44,601,193	57,719,590	60,772,720	64213,781	69,321,073
Increase of AR	38,402,012	41,713,085	43,216,529	35,199,202	47,758,796	48,849,097	47,733,319
No change	93,778,323	87,978,881	82,624,954	77,523,884	61,911,160	57,379,798	53,388,284

economies of scale, according to which small municipalities face financial and technical difficulties and have little, if any, economic incentive to implement water loss reduction projects.

Although the impacts seem timid, let us recall the poor quality of data informed to SNIS by several cities, leading to zero potential savings in many utilities, as addressed elsewhere. As an illustration, the aforementioned study conducted for Brazil revealed the economic level of physical losses ranged between 40 and 110 L per connection per day for most cities (Wyatt *et al.* 2021). Such values are much lower than any goal established by Ordinance No. 490/2021, indicating that the federal government might have started pushing the utilities too softly, which is understandable considering the complexity of WSS in Brazil, the number of connections of several water providers (in this study, 3,289 cities provide WSS for less than 5,000 connections), and the challenges that small utilities face, such as lack of measurement equipment, access to financial mechanism, and need of high-level technicians (Liemberger & Wyatt 2019). On the other hand, depending on the tariff-setting methodology – rate of return, for instance, utilities might have a low incentive to reduce NRW in function of the complexity of adapting the whole working processes and mindset (see Liston 1993 for more details about economic regulation methodologies).

Nevertheless, reducing NRW has become mandatory in the country, and utilities will need to adapt themselves to access the federal budget. Decreasing NRW demands a specific and multidisciplinary team in utilities, combining commercial, planning, and operational sectors, according to the characteristics of their water losses. Several utilities in low- and middle-income countries may find that their commercial losses have a big share in the total NRW. Although more sensitive due to social and political aspects, addressing apparent losses may not demand massive investments, since it can be done with actions such as meter reading improvements (including management and regular replacement of water meters), bill and customer management, and inspection of illegal connections. On the other hand, physical water losses require greater investments in infrastructure, and costs may be too high for several utilities. Pressure management, decrease of repairs' time, and leakage localization are very effective actions to be taken toward water loss reduction. In addition, assets management, renewal, and design are middle-term programs mandatory for long-term NRW programs (see European Union 2015; Faber & Radakrishnan n.d. for more details).

Government, regulators, and financiers have a crucial role in assuring WSS access at an affordable price. In a complex context such as Brazil, where several municipalities are responsible for WSS services, subnational regulators are set in a state base, and the leading financier is the national government, robust coordination must be in place to deliver compelling public policies, targeting measurable objectives on an appropriate scale, relying on a clear assignment of responsibility across authorities, and monitoring and evaluating the outcomes (OECD 2015). Economic regulators should promote and expected operating and investment costs in business plans focused on efficiency and universalization, as also suggested by the OECD, and environmental regulators should avoid undue water abstractions, which deplete lakes and rivers for further generations (European Union 2015). Regulators are also more than capable of collaborating with national governments regarding technical approaches, such as local targets, indication of priority cities to finance and perhaps preparation of clusters for introducing a more realistic benchmark and goals. Performance is also fundamental in places where the speed of improvements is below the expectation of society and local conditions needs. Although it seems Brazilian new water loss goals are soft regarding their impact on water affordability, the savings of energy, chemicals, and imported water are considerable, and the application of Ordinance No. 490/2021 will definitely convey the message to utilities.

4. CONCLUSIONS

Brazil faces a significant challenge toward WSS universalization, especially taking into account its macro-region inequality and cultural and socioeconomic differences. Utilities have an essential role in assuring affordable and as efficient as possible services for everyone, lowering the total cost of production and its tariff. Setting water loss goals until 2034, Ordinance No. 490/2021 is a first step to pushing WSS utilities to efficient services.

This article addressed the potential impact of the Brazilian Ordinance on water affordability indicators, including for vulnerable families, toward demonstrating efficient WSS services, which make a difference in families' budgets. The first results showed that ordinance effects on Brazil will be highly positive regarding volume savings, reaching up to 1,648,240,000 m^3, representing 16.6% of consumed water in 2034. Revenue recovery due to reduction in apparent losses outreach 7.1% of total services expenses in the same year, representing a great potential for tariff reduction or improvement projects, such as network extension to peri-urban zones.

Although the potential savings in cubic meters and the potential revenue from apparent loss reduction were impressive for the whole country, their impact on the water affordability indicators was positive only when the number of people affected was considered. In 2034, 69,321,073 people may have their affordability ratio reduced due to the savings from ordinance targets. However, considering the costs utilities will have to implement NRW programs, several cities will not perceive financial savings, due to different reasons such as low water tariffs, absence of economies of scale, or local technical difficulties. This is also shown by the increase in affordability ratio in some samples. A more significant effect was observed for vulnerable families with no access to social tariffs, which highlights the importance of poorer households' access to the discount they are eligible for. Since this study considered part of the costs in the savings calculation, the impact could be greater depending on the utilities' performance and local environment.

Nevertheless, in such a heterogeneous country like Brazil, a degree of flexibility is required for a general framework of principles and goals. Differently from water quality regulation, it is unlikely to have a 'one-size-fits-all' approach (European Union

2015). The large number of samples with zero potential for savings led to the conclusion that, besides the low accuracy of some information from SNIS, the goals of the federal Ordinance may be too soft. However, the national government should continuously push utilities to efficiency in cooperation with water regulators. Water regulators play a crucial role in stimulating a realistic technical-based efficiency scenario. Considering that Brazil has subnational WSS regulators, they are able to take into account the specific operating conditions of utilities, which would strongly affect the unavoidable water losses, the economic and sustainable level of water losses, the cost–benefit ratio, and the payback of NRW reduction actions, leading to gradual improvements on utilities functioning toward a more efficient and affordable services.

ACKNOWLEDGEMENTS

This study is part of the research activity carried out at Civil Engineering Research and Innovation for Sustainability (CERIS) and has been funded by the Portuguese Foundation for Science and Technology, under project 2022.13852.BD.

DATA AVAILABILITY STATEMENT

All relevant data are included in the paper or its Supplementary Information.

CONFLICT OF INTEREST

The authors declare there is no conflict.

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First received 16 November 2023; accepted in revised form 15 April 2024. Available online 3 May 2024