



A Comprehensive Framework for Water Affordability Analysis

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Abstract

Water and sanitation affordability has emerged as a significant concern in recent years due to economic crises and the increasing reliance on tariffs to finance public services. Governments have often depended on inadequate affordability analyses, if any, to identify constraints faced by vulnerable families in accessing water supply and sanitation services. This paper proposes a comprehensive affordability analysis framework, considering six key dimensions: coverage rates, conventional affordability ratio, community poverty conditions, affordability ratio for poorer households, access to water social programs, and the burden of connection fees. The framework was applied to Brazil, focusing on its state-owned providers, which serve more than 70% of the population. The results demonstrate that the proposed framework offers a simple yet robust tool for decision-makers globally, with the flexibility to adapt to various contexts. The case study revealed that the Brazil's conventional affordability ratio masks affordability issues faced by poorer families, along with low access to social tariffs, high incidence of poverty, and low coverage in several areas. These findings provide critical insights for stakeholders, enabling the development of targeted public policies and the design of appropriate subsidy mechanisms.

Highlights

- Conducting water affordability analysis is essential for optimizing subsidy targeting.
- The proposed framework is comprehensive and adaptable to a wide range of contexts.
- Findings from Brazil demonstrate that incomplete analysis can lead to misguided public policy decisions.

Keywords Affordability · Water Access · Public Policy · Tariff · Regulation

1 Introduction

Despite all the benefits associated with water supply and sanitation (WSS), several regions worldwide continue to lack these essential services due to various reasons, including limited political will and insufficient public budget and private investments. Globally, 2.2 billion

Extended author information available on the last page of the article

people lack access to a reliable water supply and 4.2 billion do not have safe sanitation (WHO and UNICEF 2021). The Covid-19 pandemic further exposed states' unpreparedness for economic shocks, leaving no fiscal room for unpopular infrastructure projects, such as sanitation. As a result, users' tariffs have emerged as a solution to enhance coverage and quality of public services. Although cost recovery tariffs offer clear benefits to utilities and users, WSS tariffs face challenges in meeting multiple objectives such as providers' financial sustainability and users' affordability (Pinto and Marques 2015; OECD 2020; Grafton et al. 2023). While some organizations argue potential social issues related to WSS tariff are best addressed outside the water bill (OECD 2020), affordability concerns have grown among researchers and practitioners over the past years, since salary increases often fail to match rising living costs, even in wealthier nations (Aqua Publica Europea 2016; Raucher et al. 2019). A study conducted in the United States from 1997 to 2017 reported a 130% rise in household WSS tariffs, compared to increases of 85% in rent, 68% in home energy, and 103% in healthcare, all of which exceeded the 52% rise in the Consumer Price Index during the same period (Raucher et al. 2019).

Affordability has been discussed for a while in the energy sector. However, even in well-established sectors such as energy, researchers still face uncertainties about appropriate metrics (Castaño-Rosa et al. 2019; Rademaekers et al. 2016). A review of European fuel poverty indicators suggested a combination of metrics to enhance the analysis, avoiding overlooking critical information (Castaño-Rosa et al. 2019). The WSS sector is more complex. The United Nations have recognized access to WSS as a human right including it in multiple Sustainable Development Goals (SDG) to be achieved by 2030 (WHO and UNICEF 2021), which can cost US\$ 114 billion annually (Hutton and Varughese 2016). Despite significant funding needs, the water sector is often heavily subsidized, with artificially low tariffs commonly tied to poor service quality (Andres et al. 2020), and implementing full cost recovery tariffs can significantly impact families' budgets.

Water affordability measures vary widely across studies, depending on the analysis objectives and data availability (Martins et al. 2016; Andres et al. 2020; WHO and UNICEF 2021; Fagundes et al. 2023). Measuring affordability is inherently challenging. For example, households from several low-income areas rely on multiple water sources, up to six in some cases (Hoque and Hope 2020), and income may fluctuate seasonally, especially in regions dominated by informal or agricultural work. Low- and middle-income countries do not perform regular socioeconomic surveys or censuses, and information is often dispersed across government departments stakeholders (OECD 2020; Fagundes et al. 2023). Nevertheless, the most common analysis surrounds the impact of WSS expenditures on families' income. There are several ways to calculate affordability in the literature, and differences in both numerator and denominator can significantly influence results. A review of affordability measures identified 15 different ratios across 79 studies (Fagundes et al. 2023). The review found that the main numerators were water bill, water expenditure, and water bill with volume for basic needs, representing 40.6%, 35.9%, and 18.8% of the studies, respectively, and the denominators were income, total expenditure, and disposable income, representing 65.5%, 15.5%, and 17.2% of the studies, respectively.

Self-reported expenditures can include extra costs beyond tariffs, such as additional treatment and plumbing installations (Pattanayak et al. 2005). They may also account for expenses related to alternative water sources for non-connected households, which have

been emphasized lately as an important component in low-income countries (Whittington and Cook 2019; WHO and UNICEF 2021; Martínez-Espiñeira and Pérez-Urdiales 2025). However, self-reported data rely on users' memory and perception, and on the methodology of the survey (Andres et al. 2020). Moreover, such data does not always distinguish between over- or under-consumption, potentially skewing affordability analyses (Gawel et al. 2013; Vanhille et al. 2018; Martins et al. 2019). Information on WSS subsidies, such as social tariffs or a free amount of water, might also be lost (Andres et al. 2020; WHO & UNICEF, 2021). In contrast, secondary data — such as utility tariffs and income statistics — are commonly used due to their relative accessibility and cost-effectiveness. To avoid under- or over-consumption in these analyses, some researchers have proposed a standard volume of water to meet basic needs (Barde and Lehmann 2014; Borja-Vega et al. 2019; García-Valiñas et al. 2010b; Goddard et al. 2021; Martins et al. 2019; Teodoro 2018). The value would vary in function of local culture and water availability; however, the World Health Organization (WHO) recommends 20 L per capita per day (lpcd) as a minimum for scarcity conditions, 50 lpcd for low health risks, and 100 lpcd as an optimum value, with very low health risk (Howard et al. 2020). Regarding the denominator, income seems preferable if reliable data is available, including seasonal and informal revenue (Hutton 2012; Andres et al. 2020). In addition, when available, organizations have recommended the use of income after taxes discount (WHO and UNICEF 2021). Calculation of the impact of full cost recovery tariffs is another use for affordability analysis (Fankhauser and Tepic 2007; Banerjee and Morella 2011; Nauges et al. 2015; Reynaud 2016; Janzen et al. 2016; Burt et al. 2018), and when possible, should include the standard level of service quality, based on WHO recommendations or benchmarking (Andres et al. 2020).

The affordability of WSS services can be analyzed at both the macro and micro levels. Macro level analyses focus on aggregated data, such as mean household income, while micro-level analyses examine specific income groups, family sizes, and other factors (OECD 2020). However, relying on average income figures can mask significant affordability, even in high-income countries (Martins et al. 2016; Raucher et al. 2019; OECD 2020; Cardoso and Wichman 2022). Determining what constitutes affordability is inherently subjective, especially when expressed as a percentage of household income (OECD 2020). Since other essential needs' costs vary among countries and regions, and the thresholds used are rarely related to significant investigation on the income required to afford all essential expenditures, the definition of the threshold has no consensus yet (Andres et al. 2020). Even in the energy sector, where a 10% income threshold is widely used, researchers have questioned its validity due to its origins in outdated methodologies from the United Kingdom in the 1990s (Castaño-Rosa et al. 2019; Rademaekers et al. 2016; Waddams and Deller 2015). As stated (Heller 2015), the limit for what is affordable or not should be set locally and based on a participatory process including marginalized families. To date, the suggestion has not been put into practice, and affordability analysis, if any, is still based on pre-established thresholds. The aforementioned literature review on WSS affordability revealed 90% of the studies adopted a threshold between 2 and 5% (Fagundes et al. 2023). However, the establishment of a limit for expenditure on WSS may be too inflexible for a sector with such a context, i.e., with scarce data, growing needs for investments, and interdependency with other sectors (Fagundes et al. 2023), and international organizations have started to suggest the use of “bands” rather than point estimates (WHO & UNICEF, 2021).

While monitoring affordability is essential for ensuring the right to WSS, its complexity and subjectivity require robust frameworks and methods. This paper proposes a flexible yet comprehensive framework for affordability analysis that can be adapted to different contexts by stakeholders, including governments, financiers, researchers, or utilities. The study brings a practical combination of different and specific studies about affordability indicators and provides a well structured scheme for considering affordability analyses into public policies in different decision levels. The paper is organized as follows: Sect. 2 outlines the proposed framework, Sect. 3 discusses the results of a case study conducted in Brazil, and Sect. 4 provides the conclusion and suggestions for further research.

2 Affordability Analysis and Proposed Framework

Affordability analysis often risks overlooking issues faced by poorer households, potentially leading to misguided public policy decisions. In the WSS sector, the complexity is heightened by the significant social aspects of service provision and the substantial sunk costs involved. A study has recommended minimum criteria for affordability indicators and measures, such as validity, accuracy, relevance and uptake, and feasibility (WHO and UNICEF 2021). Given the limitations of existing affordability measures, such as data availability and influence of socioeconomic local conditions, researchers agree that no single indicator can definitively determine whether WSS services are affordable (Andres et al. 2020; Raucher et al. 2019; WHO and UNICEF, 2021). Indicators should be combined to capture the multifaceted nature of affordability issues. This paper proposes a flexible framework with six components, adaptable to various contexts and objectives.

2.1 Water Supply and Sanitation Coverage

Coverage rates are fundamental for any affordability analysis, serving as a critical starting point for identifying WSS issues and informing policy decisions. Analyses should include national and local WSS access rates, comparisons of urban and rural access, or neighborhood-specific data particularly for informal settlements. Geographic analyses are invaluable for pinpointing areas with limited access to WSS, such as underserved rural regions, and tailoring policy responses accordingly (Allaire et al. 2024). Coverage metrics may account for both WSS network availability and households connected to these services.

2.2 Conventional Affordability Ratio

The percentage of WSS expenditure relative to household average income or total expenditure is the most common affordability ratio. As discussed elsewhere, updated Censuses are ideal material for income data if the methodology includes seasonal and informal income, where appropriate. Available disposable income enables localities to conduct even more precise analysis, since it considers tax expenses. When census data is unavailable, specific income and/or expenditures surveys are a practical alternative in low-income countries. Numerators may include demand estimates derived from mathematical models (García-Valiñas et al. 2010a; Sebri 2015) or average consumption and tariff data from national reports

and utilities records. Incorporating standard water consumption volumes, such as those recommended by WHO, can help mitigate inaccuracies due to over- and underconsumption.

2.3 Poverty Status

Aligned with SDG6, decision-makers must identify vulnerable population and their geographic location to ensure equitable WSS access. However, poverty measurements can vary widely between countries and may not always capture transient poverty or the unique challenges faced by displaced populations. While several countries have adopted multidimensional poverty measurements (Feres and Villatoro 2005; Alkire et al. 2021; OEA 2022), others rely on monetary ones, such as national or international poverty lines (Chen and Ravallion 2008), and relative poverty lines, as the 60% of median wage indicator used in many European countries (Feres and Villatoro 2005).

Affordability analysis can consider local poverty metrics (if any) already applied for other social assistance programs. Several countries have a well-established social assistance system for non-water services, and it is clever to apply the same or similar household data and eligibility criteria for WSS services (OECD 2020; WHO & UNICEF, 2021). For example, many localities apply cash transfer programs to households with children in extreme poverty, and the system and/or the selection criteria can be a valuable source for poverty prevalence analysis in WSS access. The number or proportion of households expected to be provided with assistance is relevant to the subsidies' design (WHO & UNICEF, 2021).

2.4 Affordability Ratio for Poorer Households

Using average income metrics alone can obscure affordability issues faced by vulnerable households. Micro-level affordability analyses are essential to capture the socioeconomic realities of these groups (Martins et al. 2016; OECD 2020). The selection criteria for poorer households should align with the previous item to optimize the analysis. In addition, since several WSS utilities already have social assistance programs, the value of the average tariff for low-income users must be taken into account. For example, social tariffs, a discount applied on residential charges, usually limited to a certain amount of water, are widespread programs applied by low- and middle-income countries. If data is available, non-conventional services' charges in poor areas, such as septic tank emptying or community taps and toilets, should also be considered.

2.5 Access to WSS Social Programs

The effectiveness of any WSS social assistant program implemented must be analyzed. While data collection can be challenging, such analyses offer valuable insights into whether these programs are reaching their intended beneficiaries. Comparing poverty statistics from item 2.3 with the number of households benefiting from WSS social programs can highlight gaps and inform improvements to program design.

2.6 Connection Burden

In regions where universalization is yet to be achieved, the financial burden of one-time connection costs, such as connection fees, pipes, water taps, and toilets (OECD 2020; Andres et al. 2020) warrants special attention. Upfront costs may be a barrier for low-income households to access the service (OECD 2020), as demonstrated in a study conducted in rural Nigeria, where 80.4% of households lacking water access were unable to afford initial costs, considering a 5% affordability threshold (Andres et al. 2020). Evidence suggests that subsidizing connection costs can be more effective than subsidizing ongoing consumption (OECD 2009). Figure 1 summarizes the proposed affordability analysis framework.

This framework provides flexibility to include or exclude specific indicators depending on the local context. For instance, the coverage indicator or connection fees' impact may be unnecessary in fully universalized area applying cost recovery tariffs. Moreover, regions with high inequality and limited WSS access require tailored analyses on poorer households to optimize subsidies. The main message is that a single indicator does not consider all factors influencing households' affordability and may lead to an incomplete and unreliable analysis.

3 Empirical Evidence

3.1 Case Study

Brazil was adopted as a case study since it is a continental country where regional disparities exist not only in socioeconomic characteristics but also in WSS access. Water supply reaches 84.2% of the total population and sanitation systems encompass only 55.8% (BRASIL 2022). The main figures for the country are displayed in Fig. 2.

The national government has established the National Sanitation Information System (SNIS in its Portuguese acronym), a self-reporting platform where Brazilian utilities submit extensive data annually. Since such reporting is mandatory to access the federal budget

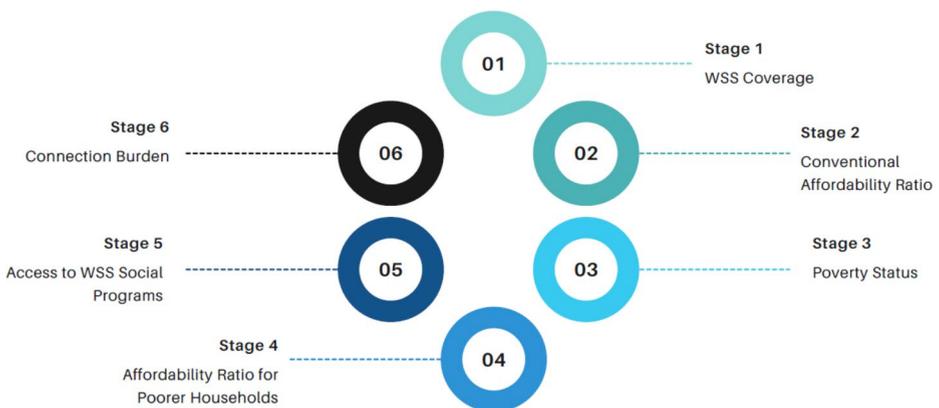


Fig. 1 Affordability Analysis Framework

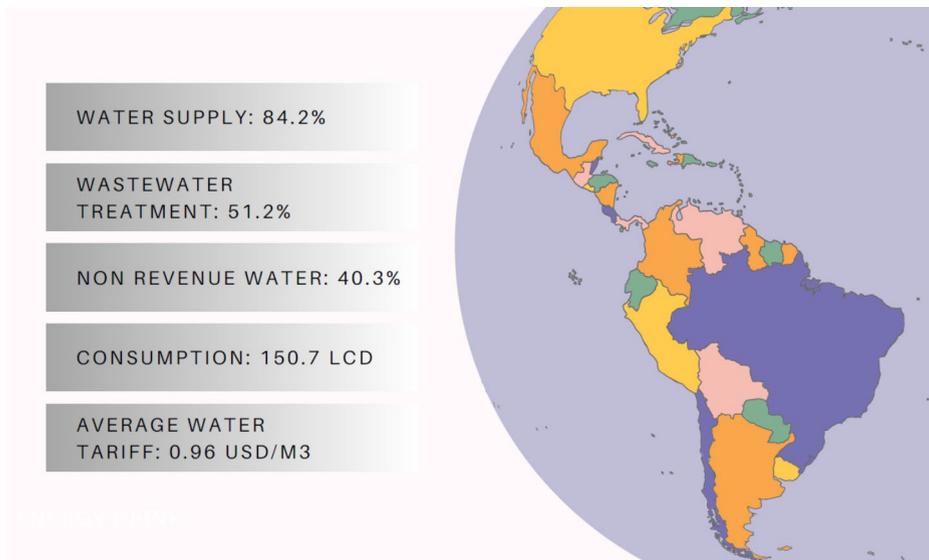


Fig. 2 Brazilian WSS sector main numbers. Source : BRASIL 2022

(including loans), 95.8% of Brazilian cities conveyed their information in 2021, which is the last available data used in this study. All the data is publicly accessible online.

Under the Brazilian Constitution, municipalities hold primary responsibility for providing WSS services, except in metropolitan areas where state involvement is required. Municipalities can deliver these services through local entities or delegate them to state-owned companies or private operators (Narzetti and Marques 2021). Aiming at economies of scale, state-owned WSS companies were created in the 1970s, primarily to support municipal service delivery. These state-owned companies remain the predominant providers of WSS services, serving over 70% of Brazil's total population (BRASIL 2022).

WSS regulation in Brazil exhibits unique characteristics. Municipalities have the autonomy to select their regulator, which can be either municipal, state-level, or regional. As a result, there are currently more than 90 regulatory entities, according to the National Water Agency (ANA)¹. Prior to the water sector reform under Law No. 14,026 of 2020, these sub-national regulators had full independence in setting tariffs, except in private-public partnerships (PPP). Given that the majority of municipalities rely on state-owned WSS companies, this study focuses on this type of provider. Additionally, due to the significant role of states capital in affordability issues, those cities with utilities other than state-owned providers were also considered.

Except for Mato Grosso, all states had their state-owned provider in 2021. In addition, the following capital cities have concession contracts with private operators: Maceio (AL), Manaus (AM), Cuiabá (MT), Campo Grande (MS), and Teresina (PI). Porto Alegre (RS) WSS utility is municipal. Therefore, the sample encompasses all the cities where those state-owned companies provide water supply and/or sanitation services, reaching 4052 municipalities, representing 72.8% of Brazilian cities, 78.9% of the total population for

¹ <https://www.gov.br/ana/pt-br/assuntos/saneamento-basico/agencias-infranacionais>.

water supply services, and 60.1% of wastewater collection and/or treatment (in several cities, the state-owned providers are only responsible for water supply).

3.2 Methods

3.2.1 Water Supply and Sanitation Coverage

The two primary coverage indicators from SNIS were used to assess WSS coverage, one for water supply (IN055) and another for sanitation (IN056). These indicators quantify the population served WSS utilities within their designated service areas, serving as key performance metrics.

3.2.2 Conventional Affordability Ratio

According to Andres et al. (2020), measuring affordability requires defining and incorporating the cost of a minimum basket of water, sanitation and hygiene (WASH) services. The present study assumes that all cities access WSS under state-owned tariffs. In addition, considering unreliable data, it is assumed that connected households receive an average quality of services.

The burden of WSS bills on the average salary was calculated using the average wage per state from the Brazilian Households Survey 2023². Since the average wage is based on individuals aged 14 years and older, family income was estimated by multiplying the average salary by the national employment rate (from the Census 2022) and the average number of household members in each city (also from Census 2022). However, due to incomplete Census 2022 report, employment rate and salaries at the city level could not be incorporated into the analysis.

The SNIS database provides the average per capita water consumption per city. By combining this data with household size, the average water consumption was calculated. A notable limitation of this approach is that larger families – often among the poorest – may not be accurately represented, as detailed Census 2022 data on such demographics is not yet publicly available. Given that Brazilian state WSS regulators have administrative independence to establish tariff methodologies, WSS bills were estimated using the tariff structures applied in October 2023 and available on utilities' websites. The Affordability Ratio (AR) is expressed by Eq. 1.

$$AR1 (\%) = 100 * \frac{WSS \text{ tariff} * SNIS \text{ Consumption}}{\frac{Hab}{HH} * Employment \text{ Rate} * Average \text{ Wage}} \quad (1)$$

where:

Hab/HH: Inhabitants per Household. Source: IBGE, 2023³.

Employment Rate: the national proportion of the population older than 14 years old with a paid occupation is 45.56%. Source: PNADC, 2023.

²<https://www.ibge.gov.br/estatisticas/sociais/trabalho/9173-pesquisa-nacional-por-amostra-de-domicilios-continua-trimestral.html?edicao=36938>.

³All the sources websites for the equations can be found at the end of this paper on 'Data Availability Statement'.

Average Wage: monthly State average wage per person older than 14 years old. Source: PNADC, 2023.

3.2.3 Poverty Status

Understanding the challenges faced by a country or locality is essential for effectively targeting subsidies. Brazil has a robust national registry for social assistance programs - *Cadastro Único* (CADÚnico), which provides comprehensive data on families living in poverty and extreme poverty. Several utilities have already used this data as a baseline for their social programs, such as social tariffs in the energy sector (Law no. 10,438 of April 2022)⁴. CADÚnico offers quantitative information of individuals living in poverty and extreme poverty per city, detailing their distribution in rural and urban areas. These insights on poverty status are critical for designing targeted interventions and are represented mathematically in Eqs. 2 and 3.

$$PP_{Urban} (\%) = 100 * \frac{\sum Low - income Population}{State Total Population} * Urban Proportion \quad (2)$$

$$PP_{Rural} (\%) = 100 * \frac{\sum Low - income Population}{State Total Population} * Rural Proportion \quad (3)$$

where,

\sum Low-income Population: sum of the total population earning less than ½ minimum wage per state.

Urban Proportion: proportion of the low-income population classified as urban residents.

Rural Proportion: proportion of the low-income population classified as rural residents.

Source for all information: CADÚnico, September 2023.

3.2.4 Affordability Ratio for Poorer Households

Despite variations in the rules applied by state WSS companies to their social tariff programs, the affordability ratio for poorer households was calculated based on an income equivalent to half the minimum wage per capita and the WSS tariff, both with and without discount provided under the social tariff. The half minimum wage threshold was used as a poverty line, consistent with practices in many WSS utilities as well as in the energy and telecommunication sectors. Additionally, CADÚnico registry can simplify the task for Brazilian managers in identifying families eligible for WSS social assistance programs. The indicators are represented in Eqs. 4 and 5.

$$AR2 (\%) = 100 * \frac{WSS social tariff * SNIS Consumption}{\frac{Hab}{HH} * \frac{1}{2} Minimum Wage} \quad (4)$$

$$AR3 (\%) = 100 * \frac{WSS tariff * SNIS Consumption}{\frac{Hab}{HH} * \frac{1}{2} Minimum Wage} \quad (5)$$

⁴ Rules available at <https://www.gov.br/aneel/pt-br/assuntos/tarifas/tarifa-social>.

Given Brazil's significant income inequality, we also sought to assess the impact on families near the poverty line but not included in social programs, adding an extra indicator using as income the 60% of the state average wage, based on previous studies (Waddams and Deller 2015).

$$AR4 (\%) = 100 * \frac{WSS \text{ tariff} * SNIS \text{ Consumption}}{\frac{Hab}{HH} * Employment \text{ Rate} * (60\% * Average \text{ Wage})} \quad (6)$$

where:

Hab/HH: Inhabitants per Household. Source: IBGE, 2023.

Average Wage: monthly state average wage per person older than 14 years old. Source: PNADC, 2023.

3.2.5 Access to WSS Social Programs

Although widely implemented by WSS utilities in Brazil, a previous study by the Brazilian Association of Regulatory Agencies reported that even eligible, many vulnerable families do not access social tariffs. This gap is attributed to various factors, such as lack of information and restrictive local regulations (Galvão Júnior et al. 2018).

In this study, the number of urban low-income families in each state (earning $\frac{1}{2}$ minimum wage or less in September 2023, according to CADÚnico) was compared with the number of households benefiting from social tariffs, based on data from SNIS. Since state-owned companies in several states do not provide WSS services to the entire population, the analysis accounted for the proportion of the population within each utility's service. The indicator is expressed in Eq. 7.

$$Social \text{ Tariff} \text{ Access} (\%) = 100 * \frac{WConnect}{SocialConnect} * StateProp \quad (7)$$

where:

WConnect: households connected to water supply, information AG033. Source: SNIS.

SocialConnect: households connected to water supply with social tariff, information TR033. Source: SNIS.

StateProp: proportion of the state population within the utility's area for water supply. Source: SNIS and Census, 2022.

3.2.6 Connection Burden

Extending networks to poorer neighborhoods may not be sufficient to ensure WSS access for vulnerable families. The costs associated with housing adaptation and connection fees can pose significant barriers, even when services are physically available. The AR calculation accounted for the connection fees charged by state-owned companies and those in capital cities. The affordability indicator was then calculated for all previously defined income levels: average state income, $\frac{1}{2}$ minimum wage, and 60% of the average state income. Both connection fees – water and wastewater – were combined for this analysis. For six utilities

that do not have fixed rates or publicly available data on wastewater connection fees, it was assumed the same value as the water connection ones. The utilities from Amapá, Santa Catarina, Pernambuco, Minas Gerais, Sergipe, São Paulo, and Paraná States and the city of Manaus apply differentiated prices to vulnerable families, which were also incorporated into the analysis. Indicators are displayed in Eq. 8 to 10.

$$CB1 (\%) = 100 * \frac{WSS \text{ Connection Fees}}{\frac{Hab}{HH} * Employment \text{ Rate} * Average \text{ Wage}} \tag{8}$$

$$CB2 (\%) = 100 * \frac{WSS \text{ Connection Fees}}{\frac{Hab}{HH} * \frac{1}{2} Minimum \text{ Wage}} \tag{9}$$

$$CB3 (\%) = 100 * \frac{WSS \text{ Connection Fees}}{\frac{Hab}{HH} * Employment \text{ Rate} * (60\% * Average \text{ Wage})} \tag{10}$$

where:

WSS Connection Fees: initial charges to connect to water supply and sanitation services. Source: case study utilities' websites.

Hab/HH: Inhabitants per Household. Source: IBGE, 2023.

Employment Rate: national proportion of the population older than 14 years old with a paid occupation, 45.56%. Source: PNADC, 2023.

Average Wage: monthly State average wage per person older than 14 years old. Source: PNADC, 2023.

Brazilian Minimum Wage: BRL 660,00 in October 2023.

3.3 Results and Discussion

3.3.1 Water Supply and Sanitation Coverage

As observed in Fig. 3, Brazilian inequalities are also translated into WSS access, reaching 96.5% of coverage rate for water supply and 89.6% for sanitation in SABESP service areas in São Paulo, in contrast with 34.9% for water supply and 3.1% for sanitation in Rondônia state.

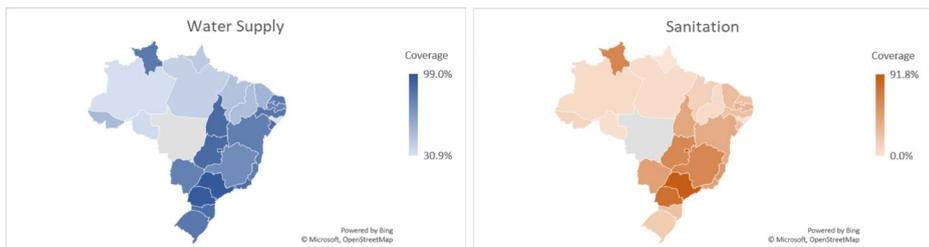


Fig. 3 Water Supply and Sanitation Coverage within state-owned companies' service areas. Source: BRASIL, 2022

3.3.2 Conventional Affordability Ratio

Measuring affordable WSS services has been discussed worldwide, since the ability to pay for every essential need is heavily influenced by local socioeconomic conditions. In line with previous studies (Andres et al. 2020; Martins et al. 2016), a 5% threshold was applied in the present one for both water supply and sanitation services. The AR was calculated for each city served by state-owned WSS provider, and the results are expressed in terms of the affected population. Figure 4 shows areas where the conventional ratio surpasses 5%, indicating the proportion of population potentially impacted. The findings suggest that most Brazilian WSS services are affordable, except for states of Rio Grande do Sul, Rio de Janeiro, and Ceará. As recommended by WHO, additional indicators were calculated using a standard consumption of 100 liters per capita per day (lpcd), as displayed in details in Appendix A: Figures 12, 13, 14, and 15.

3.3.3 Poverty Status

Figure 5 illustrates the percentage of low-income people by living area and state. These data provide critical insights into the geographic distribution of the poorest households and families, which can inform the development of universalization programs and public-funded projects, reducing the reliance on utilities' revenue generated exclusively from users tariffs. For example, 34.8% of Acre's population is considered low-income and resides in urban areas, whereas 22.9% of Piauí's population is considered low-income and resides in rural areas, requiring different public policies.

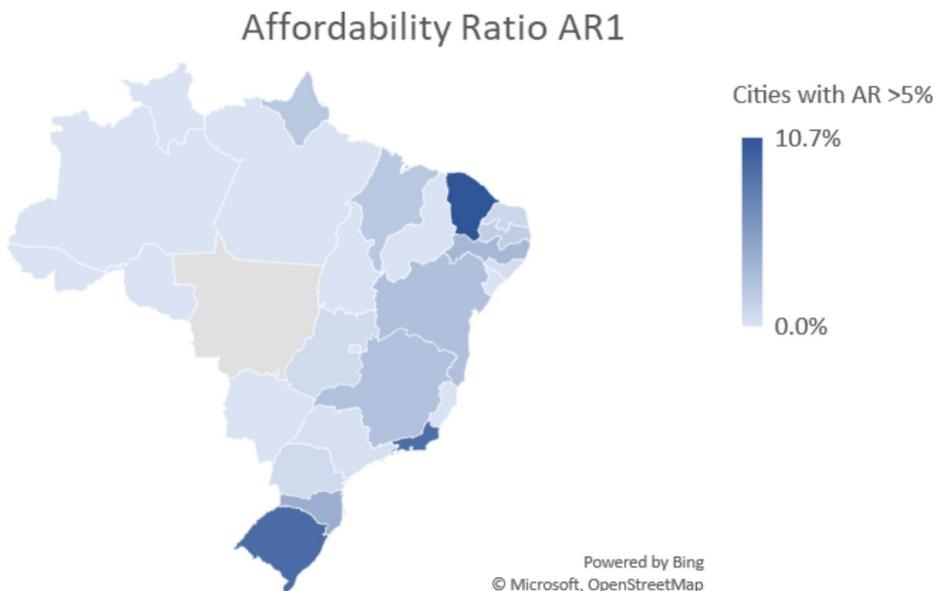


Fig. 4 Conventional Affordability Ratio

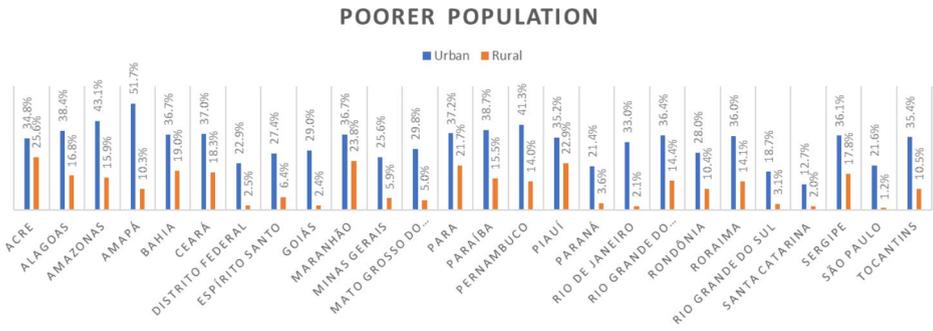
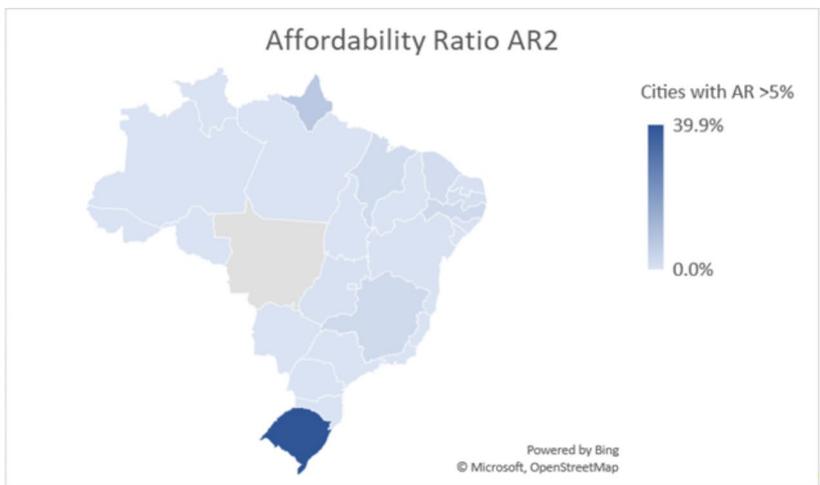


Fig. 5 Poverty Status in Brazil



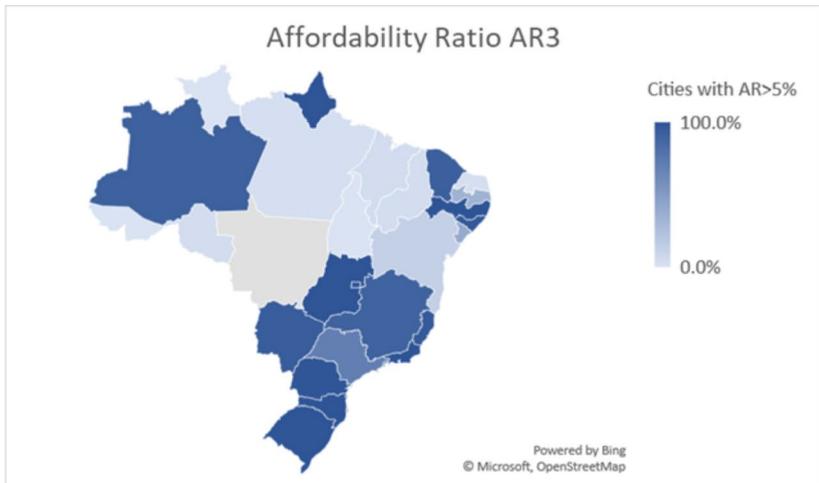
Capital of Mato-Grosso-State, Cuiabá, has AR2 = 4.8%

Fig. 6 Affordability Ratio for Poorer Households with Social Tariffs

3.3.4 Affordability Ratio for Poorer Households

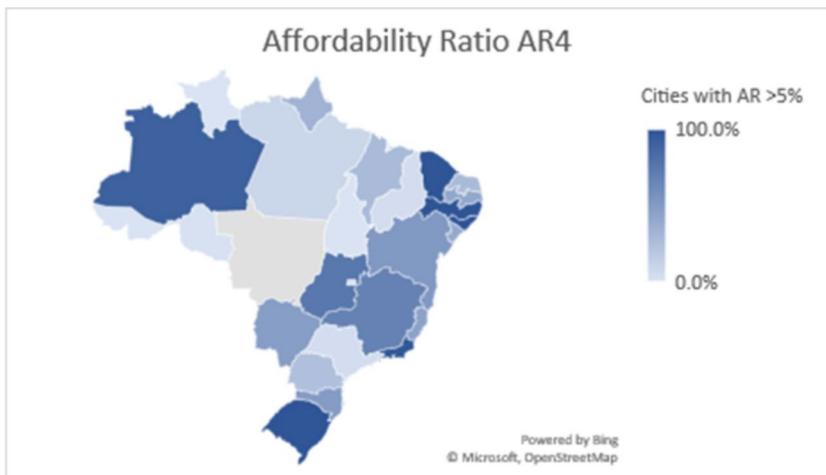
Figures 6 and 7 depict the AR for poorer households (earning less than or equal to 1/2 minimum wage), both with and without social tariff discount, based on the population served by the utility as in the Conventional Ratio. Public data indicate that COSAMA, the water provider in Amazonas, does not offer social tariff. For provider ATS in Tocantins, where the discount details were unclear, a standard discount of 50% on residential charges was assumed for this study. A comparison of the two figures underscores the significant role social tariff play in improving WSS affordability for low-income families, particularly in the southern region of the country.

Figures 8 highlights potential affordability issues faced by families near the poverty line who are not covered by social tariffs. The data reveal that in several states, a significant proportion of this near low-income households already struggle to pay their utility bills due to the lack of access to social tariff programs.



Capital of Mato Grosso State, Cuiabá, has AR3 = 7.1%

Fig. 7 Affordability Ratio for Poorer Households



Capital of Mato Grosso State, Cuiabá, has AR3 = 5.2%

Fig. 8 Affordability Ratio for Poorer Households with 60% of state average wage

As highlighted by some researchers (Martins et al. 2016; Andres et al. 2020), the use of a minimum volume would give a better idea of real affordability with no under or over-estimation. Additional indicators were calculated with 100 lpcd, as indicated by WHO, both with and without social tariff discount, as displayed in Appendix A.

3.3.5 Access to WSS Social Programs

According to Fig. 9, Minas Gerais is the state where the highest proportion of vulnerable individuals benefit from WSS discounts on their bills, yet this accounts for only 41.2% of eligible families. As discussed in other studies, access to social tariffs in Brazil remains highly restricted in several states and regulators yet to enforce measures that increase access to these benefits as part of utilities' performance criteria.

3.3.6 Connection Burden

Figure 10 illustrates the percentage of cities in Brazil where households would spend more than 5%, 10%, 20%, 30%, 50%, and 100% of their monthly income on WSS connection fees payable to utilities. Connection fees can significantly burden even families earning an average wage. This analysis assumes a one-time payment, which is uncommon for many utilities. Nevertheless, such evaluation is crucial for understanding the impact of initial costs in areas where universalization has not yet been achieved.

Figure 11 illustrates the potential impact of connection fees on poorer households for each state-owned company. In several states, low-income families may spend more than 40% of their income to cover these fees, which could result in a rise in illegal connections or a complete refuse to connect.

3.4 Policy Implications

The WSS sector is recognized as being heavily subsidized. Brazil aligns with this global trend with more than 70% of the population served by state-owned companies that rely

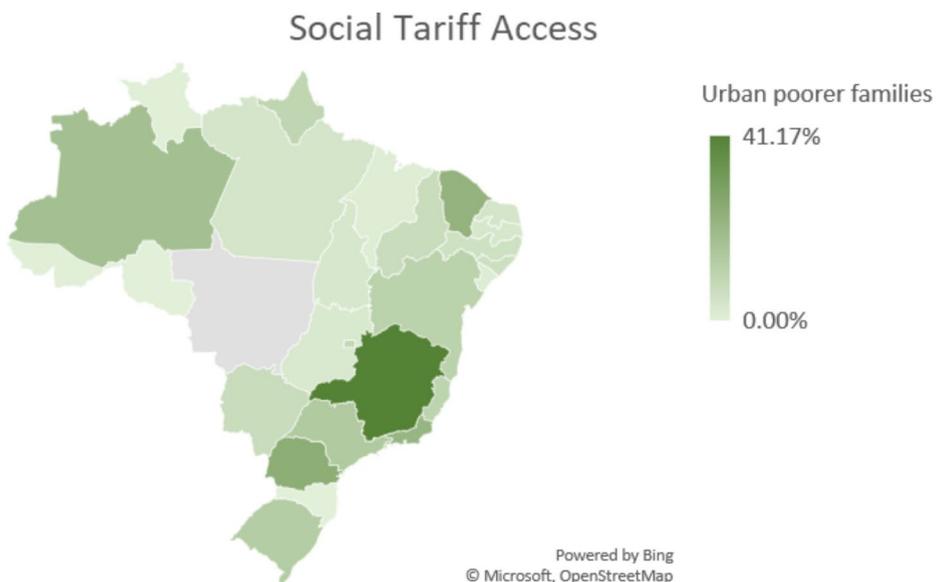


Fig. 9 Access to Social Tariffs

Proportion of Cities with Different Connection Impact

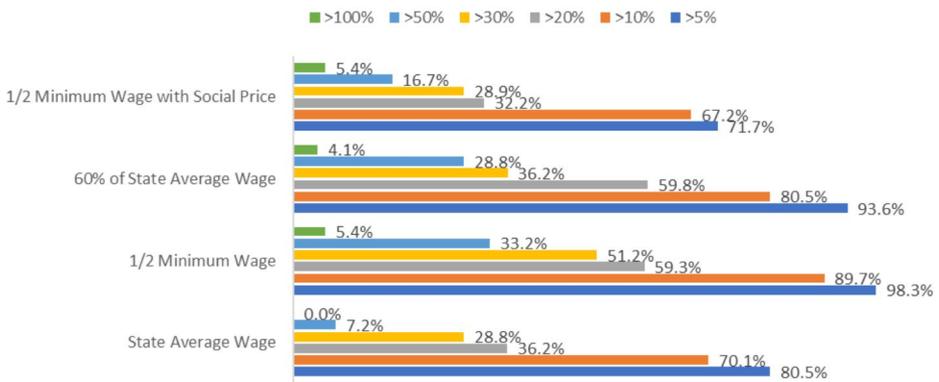
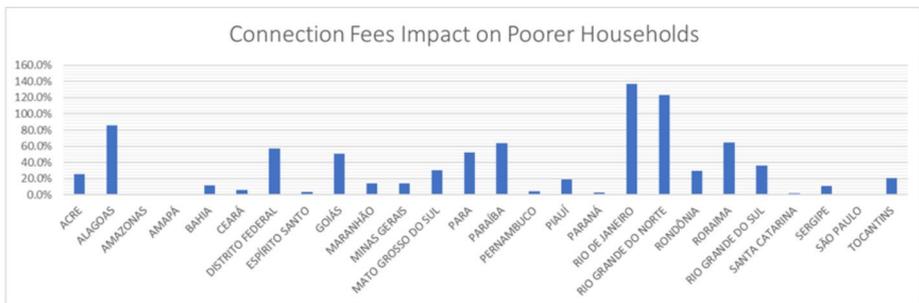


Fig. 10 Connection Burden in Brazil

heavily on federal funding, mainly for capital expenditures. The principle of cost recovery has not yet been fully implemented in many states, nor has the universalization been achieved. In 2020, Brazil enacted a new WSS law that set universalization targets of 99% for water supply and 90% for sanitation by 2033. This legislation also introduced incentives for private sector participation, emphasizing the importance of full cost recovery tariffs in the coming years and underscoring the relevance of affordability analyses in the country.

The framework proposed in this paper follows a logical progression. First, it identifies gaps in physical access to WSS services within the area of interest. Second, it calculates the affordability ratio for both average-wage earners and poorer households. Third, it quantifies the number of low-income households in need of social assistance and assesses their participation in WSS social programs, identifying vulnerable families that may have been excluded. Finally, in areas where universalization has not been achieved, it evaluates the potential financial difficulties families face with connection costs.

The findings for Brazil reveal significant disparities. The Northern region exhibits very low coverage rates, particularly for sanitation. Combined with high poverty levels in both rural and urban areas, this presents a unique challenge for utilities, potentially requiring specific programs supported by national government interventions. With the states of Amapá, Rondônia, Pará and Sao Paulo in the process of privatizing their state-owned WSS com-



Capital of Mato Grosso State, Cuiabá, has 30.5% of impact.

Fig. 11 Connection Affordability on Poorer Households

panies, and given that PPP contracts in Brazil typically apply full cost recovery tariffs and focus primarily on urban areas, these results suggest that achieving universalization by 2033 may not be feasible without exacerbating affordability issues.

The conventional affordability ratio, calculated using state-level average wages, can be further refined when city-specific Census data become available. While the conventional ratio, as noted by other researchers (Martins et al. 2016; Teodoro 2018), provides a useful initial assessment of community-wide conditions, it can obscure the challenges faced by poorer households. When a 5% affordability threshold is applied, most Brazilian WSS services are deemed affordable. However, the states of Rio Grande do Sul, Rio de Janeiro, and Ceará exhibit affordability issues even using average wages. When evaluating the potential impact on vulnerable households, the results reveal the importance of social tariffs for several states, particularly in the Southern region. Conversely, some Northern states exhibit no affordability issues even without social tariff discounts, suggesting that tariffs may be artificially low, reflecting poor service coverage.

Poverty prevalence has been identified as a crucial factor in affordability analyses (Teodoro 2018). In Brazil, this information is essential to estimate subsidy requirements and determining the appropriate strategies for addressing the issue. Quantifying vulnerable households and distinguishing between rural and urban can guide policy decisions, such as whether to develop a specific rural WSS program, maintain capital expense financing for specific states, mandate utilities to serve both urban and rural areas with tailored approaches, or if a tariff cross-subsidy would be sufficient for making WSS services affordable for all. Studies have suggested to even added gender data as part of affordability analyses (Shah et al. 2023), enhancing the evaluation towards equitable and affordable water access.

Regulators play a pivotal role in this context. Cross-subsidies are widely used in Brazil, and assessing their impact can inform governments on whether this approach suffices to guarantee affordable WSS services for all. As noted in previous studies, many states impose restrictive rules for accessing social tariffs, and regulators have yet to enforce expanded access to those benefits as part of utilities' performance (Galvão Júnior et al. 2018). This information is valuable for all stakeholders - utilities, regulators, and national and local governments. In addition, setting performance targets to utilities through regulatory acts may speed up the positive on affordability, as previous studied have demonstrated (Fagundes et al. 2024).

Finally, considering the high number of new connections required to meet the 2033 targets, this study highlights that connection fees in most states represent an impractically high percentage of household income, making one-time payments unfeasible. As addressed elsewhere, subsidizing connection fee has a greater impact on affordability than subsidizing consumption (Andres et al. 2020), and such subsidies should be prioritized in poorer localities. The framework proposed in this paper is adaptable and can be applied to various contexts beyond Brazil, depending on data availability and the objectives of the analysis. Connection costs can include housing improvements, such as toilet construction. Non-financial costs such as access time can also be included when choosing affordable technologies, but long time spent to reach water sources. Access to social programs can include other programs applied locally.

4 Conclusions

Achieving Sustainable Development Goal 6 will hardly progress if the identification of households with payment difficulties fails (WHO and UNICEF 2021). Planning WSS universalization that includes every individual must incorporate affordability analysis, either to adapt planning strategies or to optimize public subsidies. A viable financial plan should project utility revenues and rates that avoid imposing excessive financial burdens while enabling the cost-effective financing of required system improvements (Raucher et al. 2019). The robustness of the analysis heavily depends on data availability, as emphasized throughout this paper. Nevertheless, some form of study is essential to identify potential issues and address them promptly. Ideally, the appropriated threshold to classify WSS service as affordable or not should be defined through a participatory process at the national and/or local level involving low-income and marginalized population (Heller 2015). However, international standards can serve as an initial assessment tool.

The findings from this study in Brazil highlight key challenges and solutions that are applicable worldwide. In several states, the conventional affordability ratio fails to reveal the full extent of financial strain faced by vulnerable families, as demonstrated by the affordability ratio for poorer households. Moreover, access to social tariffs is significantly lower than the number of low-income families in the country, revealing gaps in the reach and effectiveness of this social assistance program. In regions like the Northern states, low WSS coverage and high poverty levels create compounded challenges, emphasizing the need for targeted public policies and investments. These findings underscore the importance of tailored interventions in underserved areas, a challenge not unique to Brazil but relevant to many countries striving for WSS universalization.

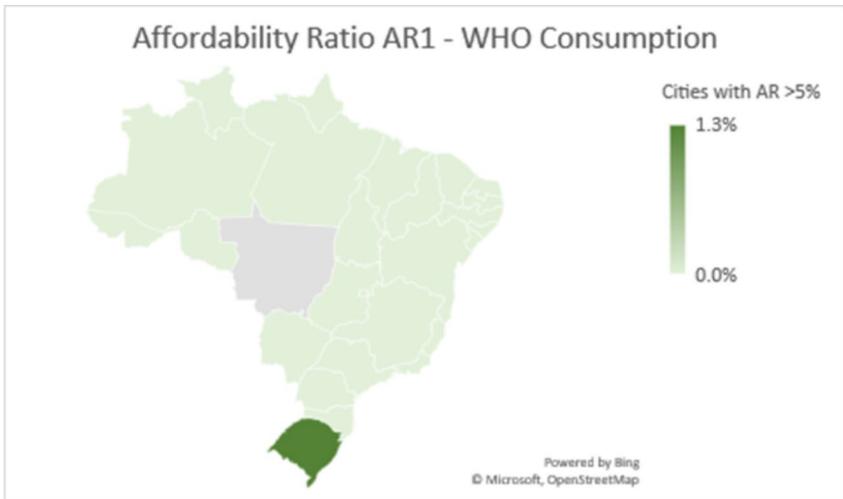
One of the key contributions of this study is the identification of practical approaches that could be adopted globally to address affordability issues. For example, combining multiple affordability indicators provides a comprehensive understanding of the challenges, enabling stakeholders to identify areas where affordability problems are most acute. The study also demonstrates that the use of national social registries, such as *Cadastro Único* in Brazil, can serve as an efficient tool for identifying and targeting vulnerable populations. Furthermore, the results highlight the importance of designing subsidy mechanisms that prioritize capital investments in underserved regions, an approach that can be adapted to other nations facing similar challenges. This model of integrating affordability analyses with tailored subsidy mechanisms and multi-stakeholder collaboration offers a pathway to universal WSS coverage that can inform global strategies.

The analysis highlights the importance of a multi-stakeholder approach in Brazil, which also has relevance for other countries. Governments should consider developing and implementing more effective subsidy mechanisms, such as funding capital expenditures for low-income and underserved areas. Utilities and local governments could collaborate to increase access to social tariffs and improve data collection and management. Regulators can also play an important by refining tariff structures subsidies and guiding financial policies based on affordability analyses.

Combining multiple indicators enhances the analysis, laying a strong foundation for subsequent management steps, such as designing and estimating subsidies and public policy approaches. This broader framework for affordability analysis can be conducted by various stakeholders, including national or local governments, utilities, financiers, or researchers. Its results can guide decision-makers toward more sophisticated strategies, enabling them

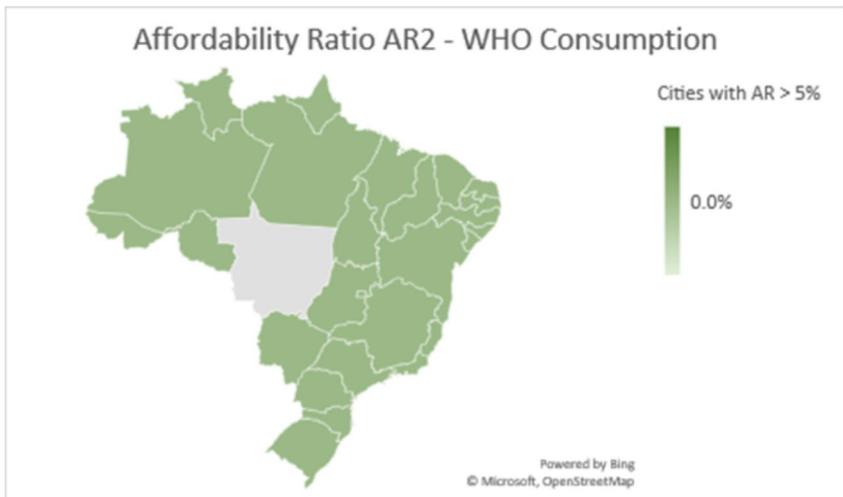
to pinpoint the scope and location of affordability challenges. The framework developed in this study is flexible and adaptable, providing a valuable tool for countries worldwide to align WSS policies with affordability goals while ensuring inclusivity and financial sustainability. Further research is needed to refine methodologies for setting affordability threshold, ensuring they align with socioeconomic realities and effectively inform policy decisions.

Appendix



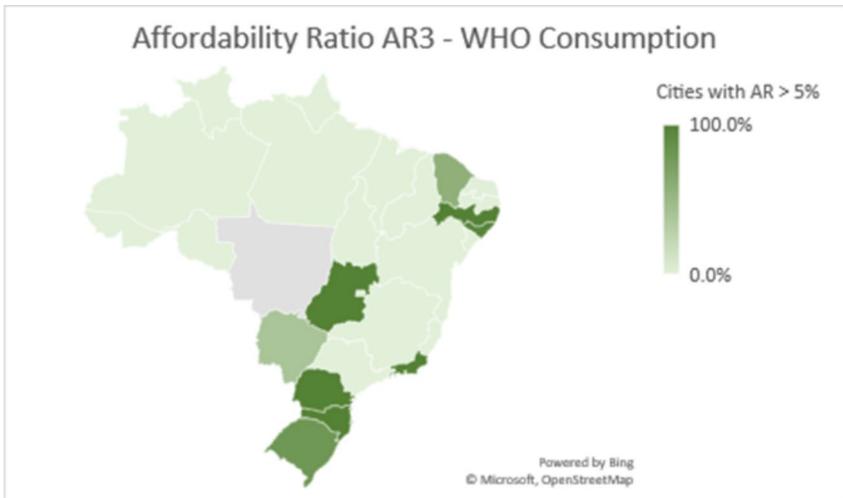
Capital of Mato Grosso State, Cuiabá, has AR5 = 2.0%

Fig. 12 Conventional Affordability Ratio for 100 liters per capita per day (lpcd)



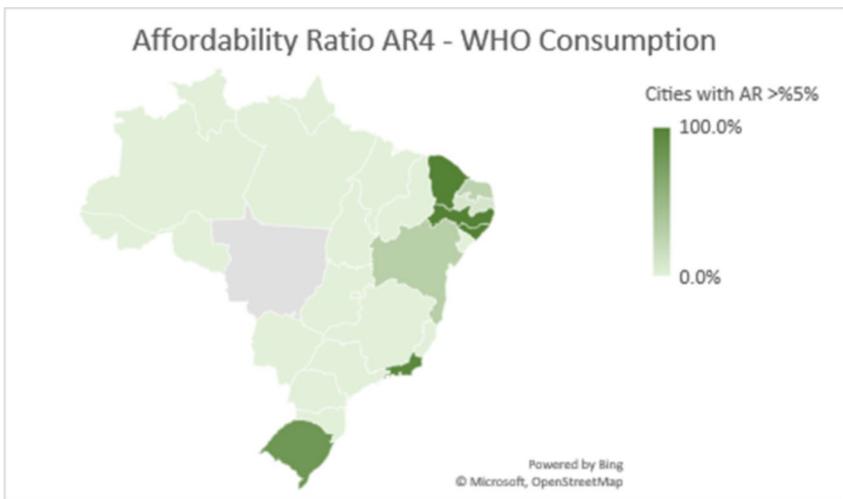
Capital of Mato Grosso State, Cuiabá, has AR5 = 2.2%

Fig. 13 Affordability Ratio for Poorer Households with Social Tariffs for 100 lpcd



Capital of Mato Grosso State, Cuiabá, has AR5 = 4.5%

Fig. 14 Affordability Ratio for Poorer Households for 100 lpcd



Capital of Mato Grosso State, Cuiabá, has AR5 = 3.3%

Fig. 15 Affordability Ratio for Poorer Households with 60% of state average wage for 100 lpcd

Authors' Contribution All authors contributed to the study conception and design. Data collection and analysis were performed by T.S.F. The first draft of the manuscript was written by T.S.F., R.C. M. and T.F. M. revised and commented on previous versions of the manuscript.

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Data Availability The data used was from public websites and papers mentioned in the article, in the reference list and below.

Inhabitants per Household (IBGE, 2023): <https://www.ibge.gov.br/estatisticas/sociais/trabalho/22827-censo-demografico-2022.html?edicao=37225&t=resultados>.

Employment Rate (PNADC, 2023): <https://sidra.ibge.gov.br/home/pnadcm>.

Average Wage (PNADC, 2023): <https://sidra.ibge.gov.br/home/pnadcm>.

Low-income Population, Urban and Rural Proportion (CADÚnico, September 2023): https://cecad.cidadania.gov.br/tab_cad.php.

Declarations

Competing Interests The authors have no competing interests to declare that are relevant to the content of this article.

Ethical Approval This article contains no studies with human participants nor animals.

Consent to Participate All authors consented to participate.

Consent to Publish All authors read and approved the final manuscript. All authors consent to publish the present study.

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