UNIVERSIDADE DE SÃO PAULO
FACULDADE DE ECONOMIA, ADMINISTRAÇÃO, CONTABILIDADE E ATUÁRIA
DEPARTAMENTO DE ADMINISTRAÇÃO
PROGRAMA DE PÓS-GRADUAÇÃO EM ADMINISTRAÇÃO

Cláudia Orsini Machado de Sousa

Guidelines for water operators to increase water resilience

São Paulo
2023

Prof. Dr. Carlos Gilberto Carlotti Júnior

Reitor da Universidade de São Paulo

Profa. Dra. Maria Dolores Montoya Diaz

Diretora da Faculdade de Economia, Administração, Contabilidade e Atuária

Prof. Dr. João Maurício Gama Boaventura

Chefe do Departamento de Administração

Prof. Dr. Felipe Mendes Borini

Coordenador do Programa de Pós-Graduação em Administração

CLÁUDIA ORSINI MACHADO DE SOUSA

Guidelines for water operators to increase water resilience

Tese apresentada ao Programa de Pós-Graduação em Administração do Departamento de Administração da Faculdade de Economia, Administração, Contabilidade e Atuária da Universidade de São Paulo, como requisito parcial para a obtenção do título de Doutora em Ciências.

Área de Concentração: Administração.

Orientador: Prof. Dr. Nuno M. M. D. Fouto

Versão corrigida

(versão original disponível na Biblioteca da Faculdade de Economia, Administração, Contabilidade e Atuária)

São Paulo
2023

Catalogação na Publicação (CIP)
Ficha Catalográfica com dados inseridos pelo autor

Sousa, Cláudia.
Guidelines for water operators to increase water resilience / Cláudia Sousa. - São Paulo, 2023.
135 p.

Tese (Doutorado) - Universidade de São Paulo, 2023.
Orientador: Nuno Fouto.

1. Water conservation. 2. Water security. 3. Water resilience. 4. Climate change. I. Universidade de São Paulo. Faculdade de Economia, Administração, Contabilidade e Atuária. II. Título.

Nome: Cláudia Orsini Machado de Sousa

Título: Guidelines for water operators to increase water resilience

Tese apresentada ao Programa de Pós-Graduação em Administração do Departamento de Administração da Faculdade de Economia, Administração, Contabilidade e Atuária da Universidade de São Paulo, como requisito parcial para a obtenção do título de Doutora em Ciências.

Aprovado em:

Banca Examinadora

Prof. Dr. ____

Instituição: ____

Julgamento: ____

Prof. Dr. ____

Instituição: ____

Julgamento: ____

Prof. Dr. ____

Instituição: ____

Julgamento: ____

To my beloved family. Especially to my husband,
André, for the endless support on this journey.

ACKNOWLEDGE

First and foremost, I am grateful for the support of my family. My husband, Andre, was by my side in every step I took during my PhD, giving guidance, mental assistance, and cheering every time I succeed. I am also grateful for my daughters, Lara and Cecília, who were born during my academic journey. They may not understand this process, but they always gave me strength to continue, even during the most difficult times.

To my parents, Lincoln and Suzana, and sisters, Mariana e Ana Carolina, who were always there for me. Moreover, my mother and my sister played an important role in my academic aspirations, as female PhDs. Also, always in my mind was my grandfather, Prof. Celso, the greatest enthusiast of environmental research in my opinion, contributing to pollution and climate change studies in Brazil for decades.

To my supervisor, Nuno, thank you for joining me in this adventure back in 2016, when I was still an undergraduate student. I am so glad our partnership lasted all these years and was so fruitful.

This dissertation was written in English, with the objective of facilitating the process of submitting the articles to publication in international journals. This was a challenge, but I was able to overcome thanks to my aunt Beatriz's proofreading and language feedback. Thank you for your time, dedication, and interest in my research.

Different aspects of this research derive from insights I had during classes. Here I name some of the professors that were responsible for such insights: Prof Luiz, Prof. Flávio, Profª. Sonia, Prof. Cláudio, Prof Jacques, and Prof. Ilan. They may not know but were crucial for the development of this work.

Finally I would like to thank all the specialists in the field of sanitation who contributed to this work, as well as to Aegea, the company I work in, for the support during this journey, encouraging and sponsoring my participation in congresses, conventions and meetings with national authorities. A special thanks to my colleague, Letícia, for the everyday cheer.

RESUMO

Sousa, C. O. M. (2023). Guidelines for water operators to increase water resilience (Tese de Doutorado). Faculdade de Economia, Administração e Contabilidade, Universidade de São Paulo, São Paulo.

No contexto das mudanças climáticas, as questões relacionadas à água se tornam ainda mais problemáticas, na medida em que as incertezas sobre a disponibilidade hídrica aumentam. Este trabalho busca oferecer subsídios às concessionárias de água e saneamento, aos governos locais, regionais e nacionais, e às agências reguladoras, para a tomada de decisões e desenvolvimento de estratégias focadas no uso consciente deste recurso. Esta tese também visa auxiliar no aprimoramento das políticas públicas e da regulação no Brasil, buscando criar resiliência e garantir a disponibilidade hídrica no país, por meio de quatro etapas: primeiro, faz-se uma avaliação do estado da arte do comportamento do consumo residencial de água; em segundo lugar, avalia-se se há influência do aumento no número de operações de empresas de saneamento privadas no comportamento de consumo de água pelo usuário final; em terceiro lugar, são identificados os principais *drivers* de perdas de água no Brasil; e, por fim, é criado um Índice de Segurança Hídrica (ITSS), para avaliar o preparo das concessionárias de água em relação a eventos hídricos extremos. Para atingir esses objetivos, foi desenvolvida uma revisão sistemática estruturada da literatura, realizadas pesquisas quantitativas, utilizando-se modelos lineares hierárquicos, e uma análise de conteúdo combinada com técnica de pontuação (score technique). Os resultados dessas quatro etapas, em conjunto, mostram que existe atualmente uma lacuna entre os trabalhos realizados nos países desenvolvidos e nos países em desenvolvimento, indicando que as soluções mais recentes e avançadas para a gestão da água, geralmente criadas no norte global, não se aplicam a grande parte das nações. Os subsídios fornecidos por este trabalho também devem contribuir para o aprimoramento do desenvolvimento de políticas públicas e de regulação que busquem criar resiliência e garantir a disponibilidade de água, não só no Brasil, uma vez que nossas conclusões partem da perspectiva brasileira, mas também para outras nações em desenvolvimento, com características sociodemográficas semelhantes. Por fim, incluímos neste trabalho dados tratados, extraídos do SNIS, um dos mais completos bancos de dados sobre saneamento do mundo. Tais dados podem ser usados por outros pesquisadores, bem como formuladores de políticas e reguladores, em avaliações quantitativas e no campo da água e saneamento.

Palavras-chave: disponibilidade hídrica, consumo de água, perdas de água, segurança hídrica, mudanças climáticas.

ABSTRACT

Sousa, C. O. M. (2023). Guidelines for water operators to increase water resilience (Tese de Doutorado). Faculdade de Economia, Administração e Contabilidade, Universidade de São Paulo, São Paulo.

In the context of climate change, water related issues become even more problematic, as water availability uncertainties increase. This work seeks to offer subsidies to W&S utilities, local, regional, and national governments, and regulation agencies, for decision-making and strategy development. This dissertation also aims at helping the improvement of public policies and regulations in Brazil, seeking to create resilience, guarantee the availability of water in the country, which is done in four steps: first, evaluating the state of the art of residential water consumption behavior; secondly, assessing if and to what extent the increase in the relevance of private companies in the sanitation market influences residential water saving attitudes; thirdly, identify the main drivers of non-revenue water; and finally, creating a Water Security Index (TWSI), to evaluate water utilities' preparedness to extreme water events. For the first step, I developed a structured systematic literature review; for the second and third steps, quantitative research was conducted, using hierarchical linear models; for the fourth step, content analyses combined with scoring technique were used. The results from these four steps show that there is currently a gap between work carried out in developed countries and in developing ones, indicating that most recent and advanced solutions to water management, usually developed in the global north, do not apply to a great part of the nations. The subsidies provided by this dissertation should also help improving the development of public policies and regulations seeking to create resilience and guarantee the availability of water, not only in Brazil, since our conclusions come from the Brazilian perspective, but also for other developing nations, that share similar socio-demographic characteristics. Finally, I include in this work treated data, extracted from SNIS, one of the world's most complete database on sanitation. Such data may be used for other researchers, as well as policy makers and regulators, in quantitative evaluations and in the field of water and sanitation.

Keywords: water availability, water consumption, non-revenue water, water security, climate changes.

LIST OF TABLES

LIST OF FIGURES

LIST OF EQUATIONS AND FORMULAE

LIST OF ACRONYMS AND ABBREVIATIONS

ANA – Agência Nacional de Águas
AP – Availability prediction
Arsesp – Agência Reguladora de Saneamento e Energia do Estado de São Paulo
BIT – Behavior influencing tactics
BNH – Banco Nacional da Habitação
CASAN – Companhia Catarinense de Águas e Saneamento
CC – Climate change awareness
CDP – Carbon Disclosure Project
Compesa – Companhia Pernambucana de Saneamento
CoP – Conference of Parts
DEA – Data envelopment analysis
DSI – Demand-side infrastructure improvements
DSM – Demand-side management
EMBASA – Empresa Baiana de Saneamento
GDP – Gross Domestic Product
GRI – Global Reporting Initiative
HLM2 – Hierarchical linear model with two levels
HLM3 – Hierarchical linear model with three levels
IBGE – Instituto Brasileiro de Geografia e Estatística
ICC – Intraclass correlation
IFC – International Finance Corporation
IoT – Internet of Things
IPCC – Intergovernmental Panel on Climate Change
NRW – Non-revenue water
PA – Preventive actions
Planasa – Plano Nacional de Saneamento
Sabesp – Companhia de Saneamento Básico de São Paulo
SDG – Sustainable development goal(s)
SNIS – Sistema Nacional de Informações Sobre Saneamento
TPB – Theory of Planned Behavior
TWSI – Total Water Security Index
UAC – User's awareness creation
W&S – Water and sanitation
WAE – Water availability evaluation
WSP – Water security plan
WSS – Water and sanitation services
WTP – Willingness to pay

TABLE OF CONTENTS

1. INTRODUCTION

The 2030 Agenda, designed by the United Nations, establishes 17 sustainable development goals (SDGs) to direct efforts to achieve a sustainable world. Goal 6 points out the need to ensure the availability and sustainable management of water, which is quite a challenge, since many countries suffer from scarcity, deterioration of quality, and contamination of water bodies, due to the unsustainable management, (Olmstead & Stavins, 2009; González-Gómez, Martínez-Espiñeira, García-Valiñas, & García-Rubio, 2012; Wang, Chang, & Liou, 2019; Ferasso, Bares, Ogachi, & Blanco, 2021; Pinto, Carvalho, & Marques, 2021). Additionally to that, as reported in the *Sixth Assessment Report of the Intergovernmental Panel on Climate Change* (IPCC, 2021), continued global warming is projected to further intensify the global water cycle, including the severity of wet and dry events, with implications for flooding or drought, being water scarcity is one of the earliest concrete signals of climate change (Santos et al., 2019). Such extreme events will become more frequent and, thus, society must create resilience to face these events.

In the context of climate change, water related issues become even more problematic, even though providing drinking water is an ancient environmental concern. As Oliveira and Ferreira (2021) point out, since the consolidation of the first cities in the world, creating and operating water systems has become an important matter. Nevertheless, the impact of global climate change, the increase of demand and the creation of drinking water availability uncertainties are becoming more frequent issues throughout the world.

There is a need to address the quality and availability of water sources, as several nations suffer from problems of water scarcity and degradation of the quality of water resources (Wang et al., 2019). There are, current, quite a few cities around the world strive to manage water resources in the face of population increases, demand for water-intensive activities and high costs (including environmental costs) of developing new reservoirs (Olmstead & Stavins, 2009).

1.1 PROBLEM SITUATION AND MOTIVATION

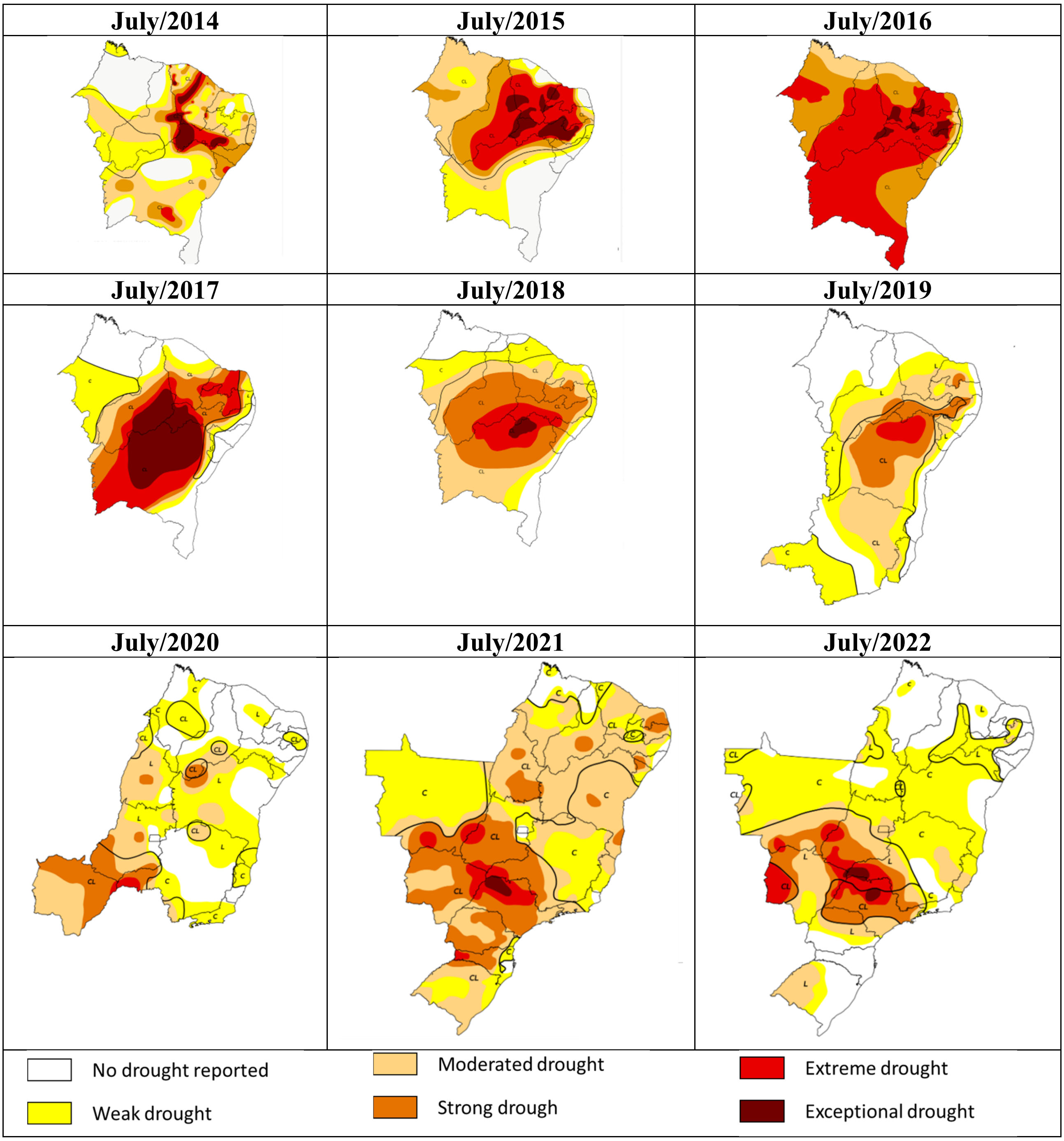
In Brazil, water is used for crop irrigation, industrial activities, power generation, mineral extraction, aquaculture, navigation, tourism, and leisure, as well as public supply, and each use depends on and can affect specific water quantity and quality conditions (ANA, 2023). That is why water availability considers the relationship between competing uses, existing resources, and infrastructure requirements (Pinto et al., 2021). In agriculture, which accounts for the greater part of water resources use, both worldwide and in Brazil, there is a higher margin for saving water; nevertheless, improvement of the management of water resources in cities is also needed (González-Gómez, García-Rubio, & Guardiola, 2011; González-Gómez et al., 2012). Considering this, the focus of this work is on urban water management, especially household water consumption.

In Brazil, recently dry events are becoming a problematic issue. Year after year, different regions within the country face extreme and exceptional drought events, as Figure 1.1 shows. Such drought events have brought adverse consequences to urban supply, changing the everyday of populations and their relationship with water, as some water utilities have reported in recent years (see some examples on Table 1.1).

Table 1.1 – Recent severe drought events in Brazil

Year	State	Description
2013 - 2015	São Paulo	In this period, São Paulo experienced the worst drought in its history: the average rainfall was the lowest recorded in more than 80 years, when the rainfall measurements were started (*Deliberação Arsesp n. 469*, 2014). Consequently, the six main springs in the state had a sharp drop in volume (Sousa & Fouto, 2019).
2017	Bahia	In 2017, the most relevant location of the Bahia State, both in economic as in populational terms, the Metropolitan Region of Salvador, experienced the worst drought in 100 years (EMBASA, 2020).
2019 - 2020	Paraná	In 2020, The rainfall regime was between 50% and 70% below average. The level of the most relevant dams in the State was at 27.5%, one of the lowest of its history and that context and that context led the state government to institute the water emergency in the state (Sanepar, 2023).
2021	Goiás	The local state administration claimed that was the worst drought in 100 years, and that it was due to intense heat and a long period of low rainfall (Saneago, 2021). This situation has compromised the public water supply.

Figure 1.1 – Drought intensity in Brazil

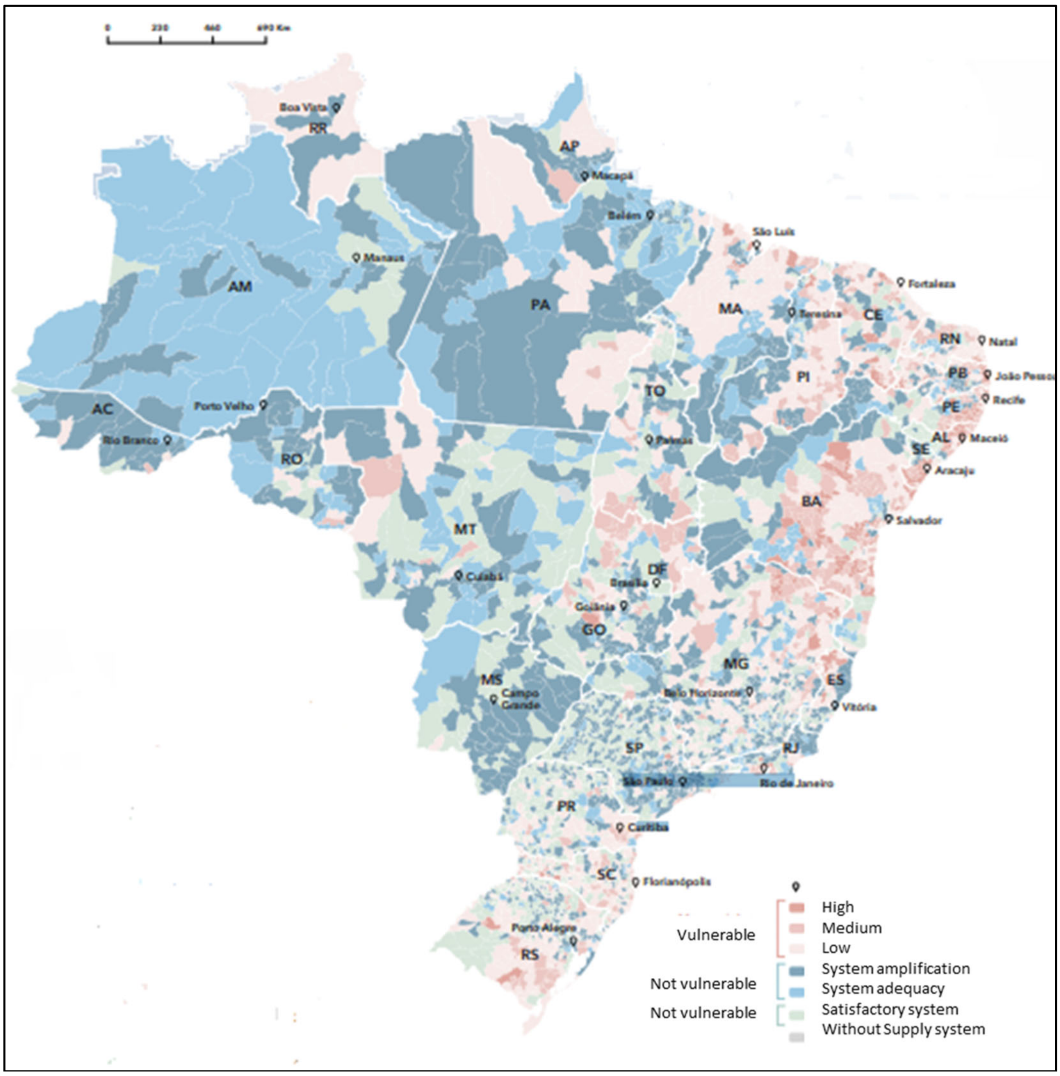


C: short impact (Agricultural and farming)
L: long impact (hydrology and ecology).
Source: ANA (2021a).

Additionally, due to the expectation of more frequent dry events in the future, the availability of drinking water in Brazilian cities is already worrisome. Data from Agência Nacional de Águas e Saneamento Básico (ANA) show that in over 44%

municipalities in Brazil are supplied by water springs classified as “vulnerable” and that 5.8 million people live in cities supplied by water springs classified as “highly vulnerable”. (information on water security in Brazil are shown on the map reproduced in Figure 1.2). This is one of the reasons why managing water demand by reducing water consumption and improving water use efficiency has become essential for ensuring water security (Aldirawi, Souter, & Beal, 2019).

Figure 1.2 – Urban water security in Brazil



Source: ANA (2021b).

Additionally to the fact that, in Brazil, water availability – due to high population density in some regions and increasing drought events – is an important issue, in the country near 35 million people do not have access to clean water and over 100 people (almost half of the Brazilian population) are not connected to the sewage network (SNIS, 2022). Also, the water and sanitation (W&S) sector in Brazil beholds great inequality:

While some municipalities have overcome universalization issues, there is a huge number of cities that require major advances to mitigate the effects of the accumulated social debt (Britto, Lima, Heller, & Cordeiro, 2012; Margulies, 2018). For instance, municipalities of the North and Northeast regions of Brazil have, in average, worse performance in the sector, compared to cities on the South and Southeast regions.

Such facts represent major barriers to achieving SDG 6 and, at the same time, extremely relevant and urgent challenges to overcome. In this context, in 2020, a new legal framework for the W&S sector was established (*Lei n. 14.026*, 2020). The major changes of this new norm include setting universalization targets for the supply of water and sewage collection and treatment, as well as the creation a regulatory environment aiming on increasing competition and stimulating private companies to enter and/or increase operation in this market. In other words, privatizing W&S services is current a trend in the Brazilian W&S market, as shown on Figure 1.3 and Figure 1.4.

Figure 1.3 – Evolution of the share of private companies in the Brazilian W&S market

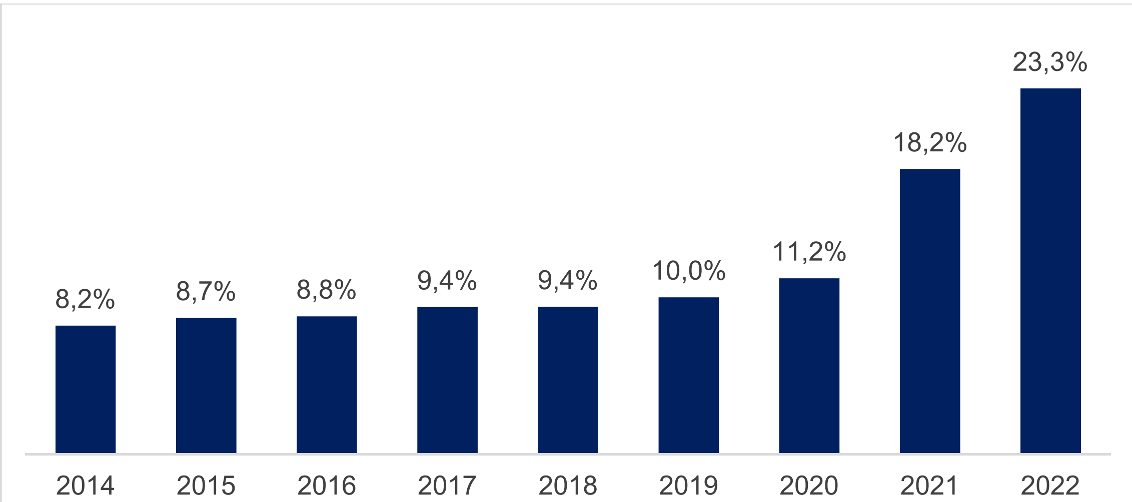
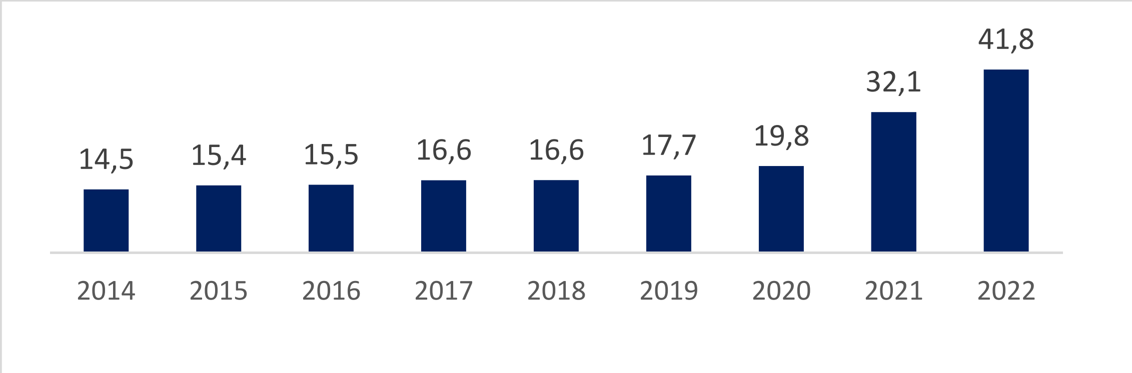


Figure 1.4 – Evolution of the population (millions people) provided by private W&S utilities



As Pereira and Marques (2022) point out, the case of Brazil emerges as an advantageous opportunity given the country's official database on financial and operational indicators on W&S services. This data base is called "SNIS" (Sistema Nacional de Informações Sobre Saneamento, in Portuguese, or National Sanitation Information System, in English) and includes Brazilian municipalities information provided by service providers or municipal bodies in charge of the management of the services. The existence of such a database, which is public and made available free of charge on the internet, may be the reason for which there is a greater number of studies addressing the Brazilian situation in comparison to other developing countries. It contains information and indicators regarding water, sanitation, solid waste, and rainfall drainage, since the Brazilian concept of sanitation includes water provision, sewage collection and treatment, as well as solid waste management and rainfall drainage (Seroa da Motta & Moreira, 2006; Barbosa & Brusca, 2015). Nevertheless, regarding the literature on water demand, allocation and even water scarcity impacts on water consumption in Brazil, despite the existence of SNIS's database, there are few studies with these focuses. Therefore, a research opportunity is evidenced, since a deepening of these issues would allow a greater basis for decision-making on issues related to water consumption in the country. **The research articles in this dissertation seek to offer subsidies to W&S utilities for decision-making and strategy development. It also aims to providing subsides for local regional and national governments, as well as regulation agencies, for public policies and regulation improvements, seeking to create resilience and guarantee the availability of water in the country**.

1.2 THEORETICAL FRAMEWORK

This dissertation is developed under the light of several consolidated theories and concepts. In this section, I present the theoretical support for the research objective, including literature on public goods, water markets, regulation, and consumer behavior.

1.2.1 Public goods

Public goods have specific characteristics: non-rivalry and non-exclusivity (Kolstad, 2011). A non-rival good can be consumed by an individual, without interference in its availability to other individuals. A non-exclusive good may not be restricted to one or several individuals. Water resources are typical examples of public goods.

From the perspective of psychology, a public good can be understood as "*a good proper to, and attainable only by the community, yet individually shared by its members*" (Dupré, 1994). With that in mind, one cannot evaluate a public good without mentioning the *Tragedy of Commons* (Hardin, 1968), which refers to a situation in which individuals with access to a public resource tend to act in their own interest and, in doing so, end up depleting such resource.

It is also important to highlight that I existence of public goods can generate the so-called externalities, a concept developed by Pigou (2013). Externalities are the effects of production and consumption activities that do not directly reflect on the market (Pindyck & Rubinfeld, 2013) and are created whenever the well-being, or the economic efficiency, of a party (organization, consumer, for example), affects another party (Bursztyn & Bursztyn; 2012). There are two types of externalities. A negative externality occurs when a third party suffers an adverse impact due to the production of a good or a service. On the other hand, a positive externality occurs when a third-party benefits from the production of a good or execution of a service by others.

Public goods and externalities can generate so-called market failures, i.e., failure to protect property rights. For Ribeiro (2014), the traditional solution to the problems of market failures is government intervention, through regulation, which seeks to change the way the market works. In environmental terms, market failures have been responsible for imbalances and degradation (Bursztyn & Bursztyn, 2012) and environmental public policies are used to correct such imbalances and reduce the degradation.

1.2.2 Water pricing

Drinking water is a natural resource and, as such, must be consumed sustainably (Gilbertson, Hurlimann, & Dolnicar, 2011). However, due to the intrinsic characteristics of public goods (which may also be called "environmental goods"), there is no market signal for water, as private goods have. Therefore, its price may be below the optimal price, as several scholars have stressed (Renzetti, 1992; Timmins, 2002; Arbues & Barberan, 2004; Olmstead, 2010).

While determining the price of water, one must consider the concept of willingness to pay ("WTP"), which is an economic concept that aims to estimate the price that a consumer is willing to pay for the water supply (Littlefair, 1998). The perception of water price varies considerably for each consumer and such variations are hardly identified by governments or agencies. As an example, WTP for water in developing countries is considered higher than in developed countries.

A proper management of water bodies used for human supply demands, among other actions, the use of economic instruments to indicate scarcity situations and to encourage the rational use of water (Oliveira & Ferreira, 2021). Indeed, charging for the use of water resources is a way to discipline the population for the use of water. Without a clear signaling of its value, water becomes a vulnerable good and is increasingly scarce not only due to natural factors, but also due to the continuous increase in demand and the lack of more rational use.

Besides its price, the use of market-based solutions is a way of inducing people to consume less water, by encouraging behavior through market signals rather than through explicit directives (Olmstead & Stavins, 2009). For instance, economic incentives – like subsides – reward consumers that act according to the public interest (Kolstad, 2011) and may be used as a solution for environmental problems that persist even if regulations based on command-and-control instruments are in place.

1.2.3 Environmental consumer behavior

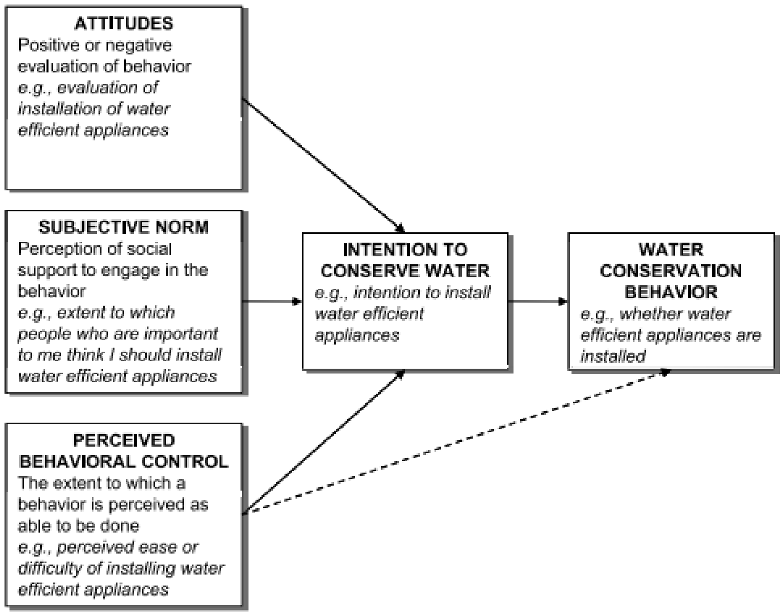
One of the main principles of microeconomics is that consumers always seek to maximize their satisfaction (or utility), which they obtain directly from the services of goods (Michael & Becker, 1973). In this sense, the Theory of Consumer Behavior explains how consumers allocate income for the purchase of various goods and services and is better understood when examined in three stages: (*i*) consumer preferences; (*ii*) budget constraints; and (*iii*) given preferences and income limitation, how consumers choose the acquisition combination that maximizes their satisfaction (Pindyck & Rubinfeld; 2013).

However, consumer's preferences are not always clear and may vary depending on the context in which choices are made. This perspective is explored in the field of research called "Behavioral Economics", which analyzes situations when consumer behavior is different from the basic premises of Theory of Consumer Behavior, once preferences are shaped by what economists call "framing" (i.e., the tendency to understand the context in which decision-making takes place).

This concept of framing is related to the Theory of Decisional Behavior, which argues that the choice of individuals varies according to the nature of the decision-making environment (Slovic, Fischhoff, & Lichtenstein, 1977; Einhorn & Hogarth, 1981; Pitz & Sachs, 1984). According to this theory, external factors, or the context, influence the judgment in relation to the value of goods and products. Bringing this perspective to the theme of this research, it is worth exploring the context of the water crisis as an element capable of shaping people's judgment in relation to the value of water.

Another theory that is present in this dissertation is the Theory of Planned Behavior (TPB; Ajzen, 1991), one of the most used theories in studies investigating the relationship between attitudes and action, and that have been used to understand decisions to engage in different behaviors, including water saving (see recent research, as Koop, Van Dorssen, & Brouwer, 2019; Mankad, Walton, & Gardner, 2019; Shahangian, Tabesh, Yazdanpanah, Zobeidi, & Raoof, 2022). Figure 1.5 presents water saving examples, analyzed by the perspective of the TPB.

Figure 1.5 – Water saving examples of the Theory of Planned Behavior



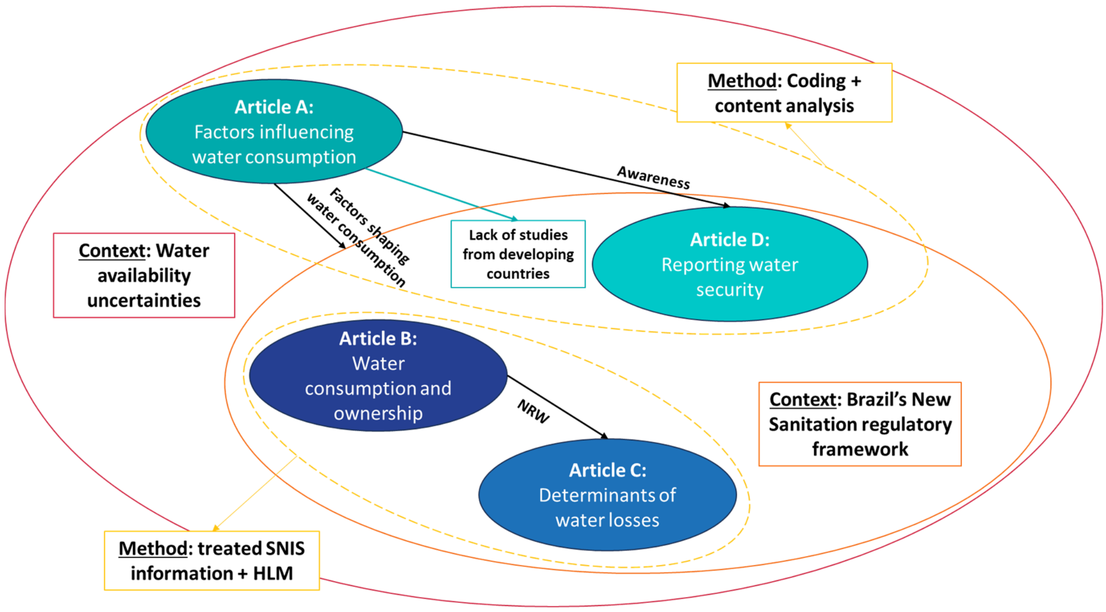
Source: Russel & Fielding (2010).

The analysis of these "pro-environment behaviors" are part of the field of knowledge that seeks to understand the types of individual actions that promote environmental sustainability (Mesmer-Magnus, Viswesvaran, & Wiernik, 2012) and there are several studies that analyze the determining factors that influence pro-environmental behaviors and activities (Corral-Verdugo, Bechtelb, & Fraijo-Sing, 2003; Trumbo & O'Keefe, 2005; Russell & Fielding, 2010). New water consumption behavior must be pursued and that was the starting point for the development of this dissertation.

1.3 STRUCTURE OF THE DISSERTATION

This dissertation is composed of four complementary articles. Each article addresses a specific research question regarding water-related behaviors adopted in times of water availability uncertainties. Although each article is independent and seeks to answer a unique question, they are interrelated, as Figure 1.6 shows.

Figure 1.6 – Interrelation among the four articles that compose the dissertation



The following sections summarize each article methodology and main results while connecting their narratives under the central goal of the dissertation.

1.3.1 Summary of Article A (Chapter 2): Why do people save water? A systematic review of household water consumption behavior in times of water availability uncertainty

Research problem: As environmental problems escalate, particularly regarding water availability, individuals' direct participation in the conservation of natural resources will be crucial to mitigate the problem. Considering this scenario, the study seeks to identify which factors influence household water consumption in the context of water scarcity.

Methodology: I collected the main literature references on residential water consumption and evaluate which factors are the main ones that shape residential water consumption behavior in drought contexts, using those factors to organize the literature. I conducted a structured systematic literature review, compounded by the following steps: (*i*) formulating the research question; (*ii*) defining the search criteria, including databases to be used, period of publication of the studies, types of publication to be considered, and string of terms to be used in the search; (*iii*) selection process; and iv) evaluating the results. Considering the results of the database search and inclusion and exclusion criteria, a total of 55 articles were selected and read in full.

Contribution: Based on an understanding of how such factors are interrelated, I propose a framework that may help future research as well as water demand-side management (DSM) policy design.

1.3.2 Summary of Article B (Chapter 3): Ownership in times of water scarcity: Are inhabitants supplied by private utilities saving less water?

Research problem: In 2020, a bill was passed by the Brazilian Congress, changing the Water and Sanitation sector's core characteristics and one expected consequence of this bill is the increase of privatizations of water utilities in the country. In this context of water scarcity and privatizing incentive, Article B seeks to help on the understanding if and to what extent the increase on the private sanitation market influences residential water saving attitudes.

Methodology: A hierarchical linear model with three levels (HLM3) was held, using data of water per capita consumption of 877 Brazilian municipalities, from 2002 to 2019.

Contribution: The results indicate that population provided by private companies tend to consume less water, and the in the article I present, based on the literature, the possible reasons for that.

1.3.3 Summary of Article C (Chapter 4): Drivers of non-revenue water in developing countries: a multilevel approach for the Brazilian case

Research problem: Brazil has been facing water scarcity in the last years, in different regions of the country and, yet the country presents one of the highest water loss levels. Article C seeks to identify the main drivers of non-revenue water in Brazil, to elucidate the reasons why NRW increased in the past years in the country as well as to present potential actions to reverse this scenario.

Methodology: A Multilevel model framework, applied to data from Brazilian municipalities water loss, was used. In the model, I included characteristics of municipality water supply infrastructure, water utilities management features and socio-demographic characteristics of the supplied population.

Contribution: I conclude that only four of the ten factors included in the model were statistically significant to explain non-revenue water (NRW): population size, share of residential consumers, network length and ownership. This indicates that one should not rely in evidence from studies conducted in other countries, where there is a different reality.

At this point, it is important to highlight that both article B and article C use information from SNIS, which may present some inconsistency, once, although it is the governmental official source, information is self-declared by municipality administrations and is not revised by the federal government or audited by a third party. That is why I considered it important to revise and analyze the collected data, before running the models designed for each of these articles. This was an important step of this dissertation.

1.3.4 Summary of Article D (Chapter 5): Disclosing water conservation: Evaluation from the Brazilian perspective

Research problem: A great part of the existing studies in the literature on the water industry focus on managerial performance, ignoring other social dimensions of the management of water resources, such as sustainability. In the water supply sector, the robustness and resilience of systems depend on "preparedness measures". In this sense, Ithe study conducted on Article D evaluated the extent to which the Brazilian water industry will bear extreme weather conditions in the future. The objective is to understand the degree of disclosed preparedness to face extreme events that may compromise water availability, and which are the most frequent and less frequent actions taken by water utilities aiming at such a goal.

Methodology: The research is built on an integrated methodological framework, associating content analysis with scoring technique, a compound technique that is usual in the analysis of the sustainability reports. I evaluated sustainability, annual or integrated reports from 15 Brazilian water supply companies, from 2019 to 2022.

Contribution: I created a Water Security Index, which includes seven classes of indicators regarding water conservation information.

2. WHY DO PEOPLE SAVE WATER? A SYSTEMATIC REVIEW OF HOUSEHOLD WATER CONSUMPTION BEHAVIOR[1]

Abstract: Continued global warming is projected to increase the severity of droughts, and, as water scarcity intensifies in different regions, water demand-side management (DSM) has emerged as an important topic. In this study, We present an overview of recent research on the factors that influence water consumption behavior, considering the scenario of global water availability changes. To do so, we reviewed 55 articles, published from 2010 to 2022, that focused on water consumption behavior in a drought context. In the reviewed articles, we identified six factors that are most frequently addressed in the literature: behavioral factors, water-saving technologies, awareness, water availability context, socioeconomic/demographic characteristics, and governmental policies. Based on the analysis of the findings in the literature regarding these factors, we developed an integrated framework that clarifies how they are interconnected and influence household water consumption.

Keywords: Behavior, water consumption, demand-side management, household, water scarcity.

2.1 INTRODUCTION

As reported in the Sixth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC, 2021), continued global warming is projected to increase the severity of droughts. Extreme drought events will become more frequent; hence, society must develop resilience to face this new reality, including enhancing actions to promote water conservation. Such actions are much needed because drought conditions and water conservation are closely intermingled (Echeverría, 2020).

As environmental issues continue to escalate, particularly regarding climate change and water, individuals' direct participation in the conservation of natural resources will be crucial to mitigate the problem (Wolters, 2014). Considering that, and as water scarcity intensifies in many regions, current interest has shifted from an emphasis on water supply

[1] Co-author: Nuno M.M.D. Fouto. A first version of this study was presented on an oral presentation at the XXIV Engema, in São Paulo, Brazil, in November/2022, and a second version, on an oral presentation at the Efficient 2023 Conference - IWA, in Bordeaux, France, in September/2023. The final version was submitted, in October/2023, to the journal "Aqua - Water Infrastructure, Ecosystems and Society" (Impact Factor: 4.3), as suggested by the scientific committee of the Efficient 2023 Conference – IWA.

to a more balanced vision considering demand as well, through water demand management (Al-Zahrani, Baig, & Straquadine, 2013). For such a shift in water conservation goals to be successful, a better knowledge of the factors that affect domestic water demand is necessary (Villar-Navascués & Pérez-Morales, 2018).

Considering this scenario, this review seeks to answer the following question: which factors influence household water consumption in the context of water scarcity? To do so, we collect the main references on residential water consumption and evaluate which factors are more relevant to shape residential water consumption behavior in drought contexts, using those factors to organize the literature. Based on an understanding of how such factors are interrelated, we propose a framework that may help future research as well as water demand-side management policy design.

2.1.1 Water scarcity

Water scarcity is a general state of water insufficiency (Oki & Quiocho, 2020). The term "water scarcity" refers to the condition in which demand for water cannot be fully satisfied, generally due to the quality of the water or the impact of water use on supply (Liu et al., 2017; IPCC, 2022). Physical water scarcity may be defined as the insufficiency or lack of water itself (Oki & Quiocho, 2020), which is usually seen in densely populated arid areas (Rijsberman, 2006). There is also an economic type of water scarcity, associated with inadequate infrastructure development and poor management as well as cases of inequitable water allocation and access across economic levels (Oki & Quiocho, 2020; IPCC, 2022). Finally, water scarcity may be related to the availability of water of acceptable quality, and, in this sense, water scarcity can be reduced through improved wastewater treatment, reductions in pollutant emissions and increasing water reuse within and among sectors (Van Vilet, Florke, & Wada, 2013).

Water scarcity and household water consumption have received increasing attention on national public agendas (Inman & Jeffrey, 2006), as well as in academia (Liu et al., 2017), for the last two decades. The reason is not only that nearly half of the world's population is currently experiencing severe water scarcity for at least some part of the year due to climatic and non-climatic drivers (IPCC, 2022) but also that water shortages are a significant social and economic issue in many countries (Lowe, Lynch, & Lowe, 2014). Understanding water scarcity is important for formulating policies at local, regional, and national scales (Liu et al., 2017).

2.1.2 Water demand-side management

Al-Zahrani et al. (2013) define DSM as a managerial approach that aims to meet the demand for water through the application of necessary and efficient measures and incentives to achieve fair and effective utilization of water. DSM can be used to reduce water consumption during daily peak use (Beal, Gurng, & Stewart, 2016) and to change long-term water consumption behavior (Koop et al., 2019). DSM is essential to ensure the availability of water resIurces (Ibáñez-Rueda, Guardiola, & González-Gómez, 2021).

DSM can be related to economic sectors, such as industry or agriculture, but may also target households, i.e., small groups of people who live together and share living arrangements (Rees, Clark, & Nawaz, 2020). In the domestic sphere, water consumption is largely conditioned by the habits and behaviors of individuals (Ibáñez-Rueda et al., 2021), and, in this sphere, DSM campaigns usually involve the co-implementation of several tools, such as technological, financial, legislative, and educational tools (Inman & Jeffrey, 2006). DSM programs can be expected to reduce water consumption, but their success depends on the type of approach used (Renwick & Green, 2020).

2.1.3 Previous systematic reviews

A literature review usually aims to reveal trends, relations, inconsistencies, and gaps in the literature as well as to organize and evaluate work in a particular field (Hahn & Kühnen, 2013). We identified four systematic reviews related to this research that only partially overlap. The reviews found during our search were developed in recent years, dating from 2019 to 2021.

For instance, Koop et al. (2019) analyzed 58 papers, including empirically oriented studies that investigated how different behavior influencing tactics (BITs) can stimulate domestic water conservation behavior. From these studies, they identified eight key reflective, semi-reflective and automatic BITs that proved to be crucial: knowledge transfer and increasing self-efficacy (considered reflective BITs); social norms, framing and tailoring (considered semi-reflective BITs); and emotional shortcuts, priming and nudging (considered automatic BITs).

A systematic review regarding demand-side management instruments was carried out by Roshan and Kumar (2020), who reviewed 16 articles and presented an analysis of end-use behavior that focused on six end uses: toilet flushing, shower/bathtub, dishwashing, indoor taps, laundry, and other/leaks. Abu-Bakar, Williams and Hallett (2021) also held a systematic review with a similar topic, but focused on water consumption measurement, such as “micro-components”, “end use analysis”, “smart meters” and “data-loggers”.

Finally, Echeverría (2020) analyzed 65 articles to understand the social dimensions driving the adoption of water-saving behaviors in urban households, focusing on the variations of water management strategies in different regions of the world. After presenting five key social categories of analysis reported in the literature — (*i*) water prices, (*ii*) water-saving devices, (*iii*) inflation of self-reported water savings, (*iv*) intention/behavior gaps and (*v*) weakening of water reductions — the author concluded that strategies to limit water consumption patterns are related to the availability of technological advances, time allocation preferences and the implementation of home appliances. This author also highlighted that in both developing and developed countries, there is behavioral regularity reflecting a gap between intention and effective behavior in conserving water in households.

2.2 MATERIALS AND METHODS

To understand the state of the art of residential water consumption in water scarcity contexts, we developed a structured systematic literature review. Structured literature reviews reduce researcher bias and enable results to be reproduced (Pickering & Byrne, 2014) additionally, they provide collective insight into a field (Tranfield, Denyer, & Smart, 2003). For our literature review, we used the following steps, adapted from the procedures of Tarne, Travezo, & Finkbeiner (2017): (*i*) formulating the research question; (*ii*) defining the search criteria, including databases to be used, period of publication of the studies, 36ublicationublication to be considered, and string of terms to be used in the search; (*iii*) conducting the selection process; and (*iv*) evaluating the results.

2.2.1 Formulating research question

The objective of this study is to present an overview of recent research on the factors that influence water consumption behavior, considering the scenario of global water availability changes. Thus, the following research question guided the structured literature review: which factors influence household water consumption in the context of water scarcity?

2.2.2 Defining search criteria

For the search, we used the Scopus and Web of Science databases. These two databases were chosen because they are considered the main sources for citation data and enable interdisciplinary coverage (Mongeon & Paul-Hus, 2016), which is important to this research due to the multidisciplinary character of environmental behavior and studies on natural resource use.

We considered publication from 2011 to 2022 in our inclusion criteria. We chose to include articles from 2011 on, since this was the year after the one when water was at the center of international discussion, particularly because of the Conference of Parts, the CoP16, that was held that year in Cancun. The event brought the theme "water management" to a global discussion after it had been left out of CoP15, in Copenhagen. Additionally, as White, Matthews, Lexén, Widforss, & Rodriguez (2017) pointed out, in 2010, awareness of the severity and intensity of realized and potential climate impacts on water began to seep into technical and political circles. The last year of the selected period of research was 2022, the year before the present work was conducted.

Only research or review articles were considered, all in English. In the string used in our search, we considered words and terms (and their variant forms) related to urban residential water consumption and water scarcity. Finally, the defined string was searched in titles, abstracts and/or keywords.

2.2.3 Selection process

In total, 67 articles were found in Scopus and 55 in Web of Science, adding up to 122 articles published in English, between 2011 and 2022. However, 34 of these documents were duplicated.

The selection process began with the analysis of the articles' titles and abstracts. From this first analysis, papers that did not focus on residential water consumption behavior or those that did not analyze a specific case of water scarcity were excluded.

After titles and abstracts were analyzed based on the previously defined inclusion and exclusion criteria, a total of 55 articles were selected (Figure 2.1) and read in full.

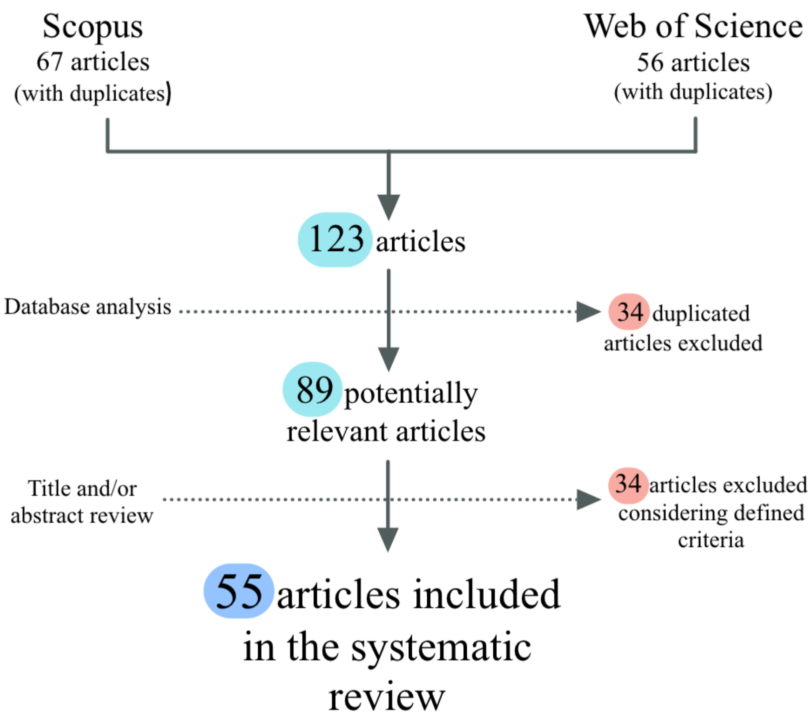
To enhance the reliability of the research, two researchers (i.e., the coauthors) conducted the analysis, following Klewitz and Hansen (2014).

2.2.4 Evaluation of the literature

For the last step of the review process, we used the recommendation for literature analysis by Klewitz and Hansen (2014), including a descriptive analysis using categories that describe the papers in terms of year of publication, type of study, country where the research articles were developed and journal of publication. This descriptive analysis (which may also be referred to as bibliometric analysis) is suitable for science mapping when there are voluminous, fragmented, and controversial research streams gradually extending to all disciplines (Aria & Cuccurullo, 2017).

Additionally, for the evaluation of the literature, we conducted a content analysis, implementing coding followed by the interpretation of the coded content (Gaur & Kumar, 2018). The focus of the content analysis was classifying the objective of each analyzed article (Navarrete, Borini, & Avrichir, 2020).

Figure 2.1 – Article selection process



Annex I brings the Research Protocol, summing up the steps of this research.

2.3 RESULTS AND DISCUSSION

The results are divided into two parts: first, we provide a quantitative descriptive (bibliometric) analysis to present an overview of the characteristics and developments in the field of the studied topic. Then, to illustrate the current state of knowledge regarding the influence of water scarcity on residential water consumption behavior, we present a qualitative thematic analysis of the literature to address the determinants of such behavior and discuss the main research findings.

2.3.1 Descriptive analysis

We started the descriptive analysis with the distribution of publications by year and, as shown in Figure 2.2, there were highs and lows. Nevertheless, over two-thirds of the reviewed articles (38 out of 55) were published in the second half of the considered period (2017-2022). The year 2021 was an outlier, with 14 publications related to the studied topic.

Articles regarding water consumption behavior in the context of droughts are usually published in journals that focus on either water issues or environmental/sustainability issues. There is no journal that concentrates publications on this subject, but “Water”, “Sustainability”, and “Journal of Environmental Management” were dominant (each with four articles from those included in this systematic review), followed by “Water Science and Technology: Water Supply” (with three articles) and “International Journal of Water Resources Development” and “Journal of Cleaner Production” (with two articles each). The remaining 36 articles were published in 36 different journals.

Most of the studies analyzed in this review were based on case studies (single, illustrative, and multiple case studies). Official databases were mainly used to collect information for the research, but some papers were based on surveys (11), and one was even based on focus group interviews. Most of the analyses used quantitative approaches - usually regressions - to identify factors impacting water consumption, but some used multiple methods, systematic reviews, and research based on experiments.

Usually, the studies analyzed a particular region in a limited period. The case study venues were located mostly in developed countries (37 articles), with the USA, Spain and Australia being the countries with the most published studies regarding household water consumption behavior (Figure 2.3).

Figure 2.2 – Number of publications per year

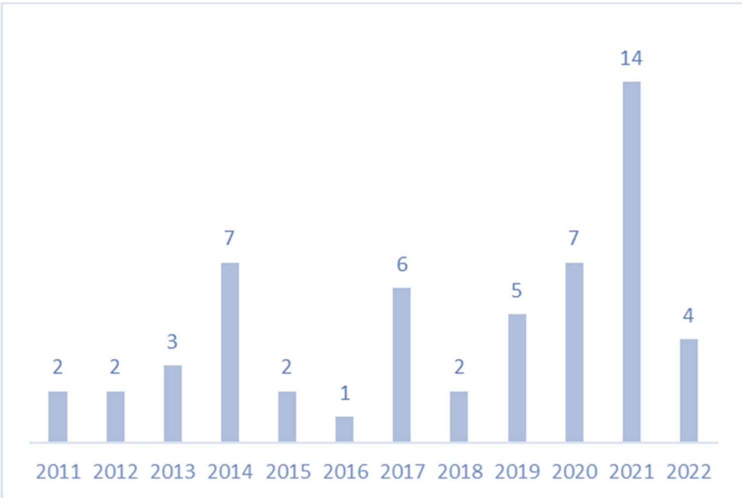
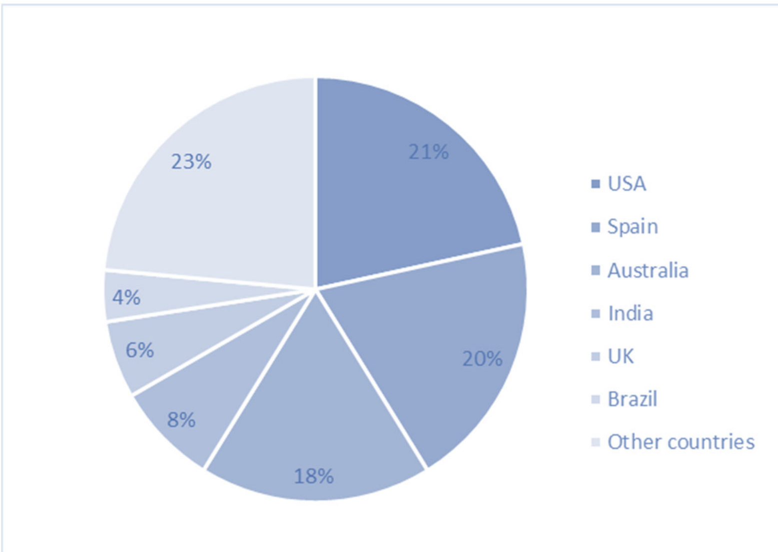


Figure 2.3 – Countries most analyzed in the selected articles



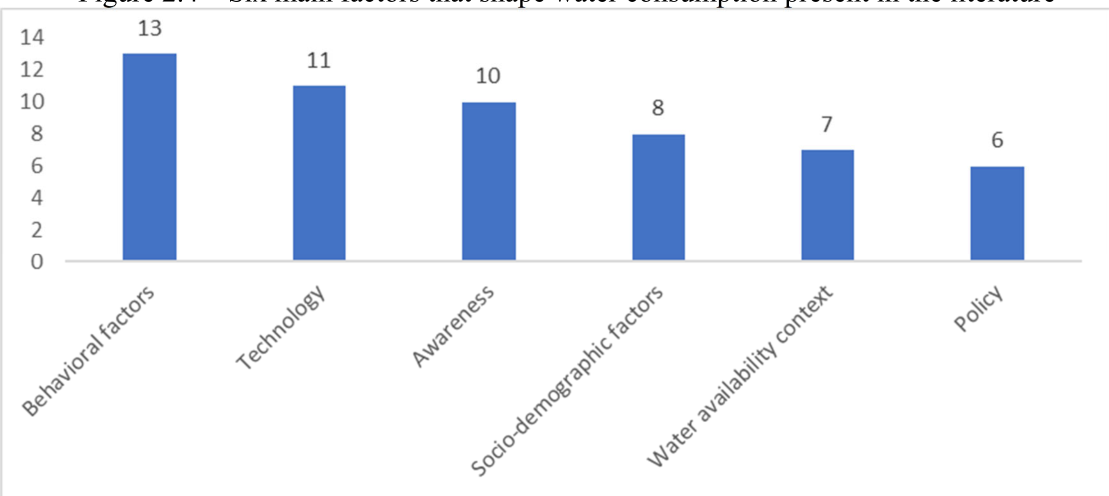
2.3.2 Content analysis – Main drivers of water consumption in a water scarcity context

Overall, the literature points to six main factors that shape water consumption (Table 2.1): (*i*) behavioral (or psychological) factors; (*ii*) water-saving technologies and devices; (*iii*) water availability context; (*iv*) awareness creation (through information and education); (*v*) policy drivers for water saving; and (*vi*) socioeconomic and demographic factors. There is no trend of a specific topic being studied in one particular year or in a sequence of years, meaning that all six water consumption factors present in the literature were distributed over time during the period of analysis. A relevant fact, however, is that developed and developing countries differ in terms of the most analyzed topics: the top three factors that influenced water consumption studied in developed countries were behavioral factors, water availability context and awareness, while the top three in developing countries were technology, sociodemographic factors, and policy.

Table 2.1: Main factors that shape water consumption

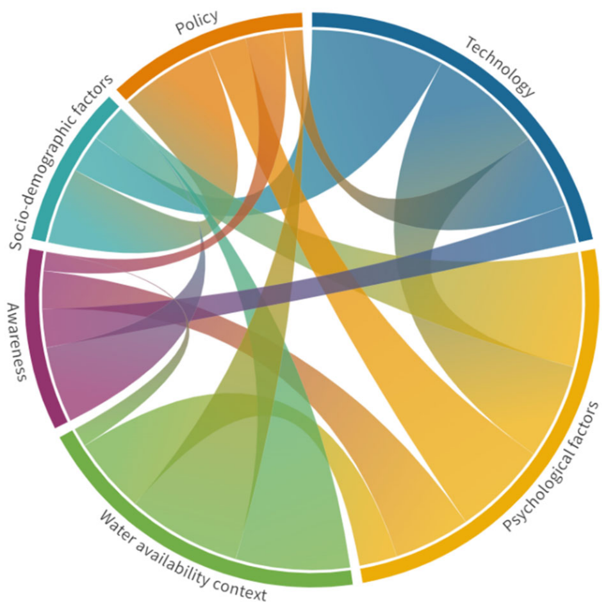
Factor	**Characteristics**
Behavioral (or psychological)	Perceptions of water rights, environmental threats, social desirability, beliefs, attitudes, and emotions.
Water-saving technologies and devices	Adoption of technologies and devices that aim to save water
Water availability context	The experience of water scarcity events.
Awareness creation	Creating awareness regarding water consumption issues through information, educational campaigns, and benchmarks and feedback.
Policy drivers for water saving	Rules and regulations seeking to reduce water consumption.
Socioeconomic and demographic	Socio, economic and demographic characteristics of the population in a specific location.

Figure 2.4 – Six main factors that shape water consumption present in the literature



The six factors found in the literature were mingled, as was evidenced by the consideration of more than one of them in each article analyzed in this literature review. The relations between the multiple factors, as found in the papers analyzed, are shown in Figure 2.5. In this figure, each color represents the factor that had a major role in each paper. The lines connecting two topics link two different factors explored in the same paper, and the thickness of the lines represents how many times that link appeared in the literature search. For example, a great number of papers that focused on “technology” (darker blue lines) also explored sociodemographic (light blue lines) and behavioral factors (yellow lines), while fewer papers with the same focus explored policy (orange lines) or awareness (purple lines).

Figure 2.5 – Relation between the factors that influence household water consumption



2.3.2.1. Behavioral (psychological) factors

Behavioral factors were the main topic in 13 out of the 55 studies from the present review. We considered behavioral factors to be those related to perceptions of water rights, environmental threats, social desirability, beliefs, attitudes, and emotions that may impact household practices around water consumption (Radonic, 2019; Ibáñez-Rueda et al., 2021).

A few theories were related to psychological factors, but the most cited in the reviewed articles was theory of planned behavior (TPB). TPB, was proposed by Ajzen

(1991) and brought up by some of the analyzed articles (Koop et al., 2019, Mankad et al., 2019; Shahangian et al., 2022). According to this theory, people are likely to engage in a particular behavior if they think their peer group (i.e., people whose opinions they value) expects them to act in such a manner and hold a positive attitude toward that behavior (Mankad et al., 2019). In this line, peer pressure for water saving might be more effective than government incentives, which is why understanding and being able to shape neighborhood effects might become a useful lever to facilitate initiatives aimed at promoting community engagement (Wang & Dong, 2017).

Peer pressure can also be referred to as social norms, and in recent years, social norm research has emerged in the water conservation literature because of the key role of social norms in individual attitudes toward water saving (Wolters, 2014; Mankad et al., 2019; Wang & Dong, 2017; Ibrahim et al., 2018). Personal and social norms are used in the pro-environmental behavior literature to examine people's sense of moral obligation to perform environmentally correct actions (Mankad et al., 2019), including water saving. The impositions of social norms are important to create a long-standing water-saving culture in communities (Wang & Dong, 2017).

Environmental concern is also a strong candidate for influencing water consumption. Nevertheless, environmental concern alone is not a strong predictor of environmental behavior (Wolters, 2014). Previous research has shown that understanding water issues in the community is an important element for solving water-related problems (Wang & Dong, 2017), however, varying human judgments — for instance, concerns about water scarcity — are best predicted by different sets of sociocultural factors. This finding supports the value of multifaceted approaches to understanding public perspectives on complex environmental challenges (Larson, Wutich, White, Munoz-Erickson, & Harlan, 2011), such as water scarcity.

Proximity to nature, whether physical or psychological, may also interfere with people's water consumption behavior (Wolters, 2014; Ibáñez-Rueda et al., 2021). Thus, the potential of natural connectedness to change water use patterns should be considered, and interventions that strengthen individuals' relationship with nature by reinforcing their feelings of connectedness could be a good strategy (Ibáñez-Rueda et al., 2021).

2.3.2.2. Water-saving technologies and devices

One way to reduce water consumption is through the adoption of technologies and devices that aim to save water. In this review, one-fifth (11 out of 55) of the analyzed articles had “water-saving technologies and devices” as the main topic, and another 12 included water-saving technology in their analysis, but not as the main topic. Corroborating Edirisinghe and Pathirana’s (2021) conclusion, that there has been increasing interest in this matter in the literature, in our review, two-thirds of the articles that focused on technological factors were published from 2019 on.

Understanding the determinants of the adoption of water-efficient devices is an important step toward the development and incorporation of technological policies, particularly policies seeking to reduce water consumption. That is why such an understanding is commonly addressed in the literature (see Martínez-Espiñera & García-Valiñas, 2013; Ramsey, Berglund, & Goyal, 2017; Koop et al., 2019; Radonic, 2019; Rule, Parker, Majikijela, & Lunga, 2021), particularly when related to some of the most used technologies, such as dual-flush toilets, flow-control devices, water-saving dishwashers or washing machines with lower water consumption and devices and methods for grey-water collection and use (Martínez-Espiñeira & García-Valiñas, 2013; Abu-Bakar et al., 2021).

The acquisition and use of water-saving devices depend on socioeconomic and demographic factors, such as education, financial capacity, and age (Martínez-Espiñeira & García-Valiñas, 2013; Rule et al., 2021). Acquisition may be intensified by policies that encourage the adoption of water-saving devices, such as subsidies (Martínez-Espiñeira & García-Valiñas, 2013), and by water availability context (Stone & Johnson, 2022). However, it is worth keeping in mind that water conservation behaviors that require little effort are most common, while conservation behaviors that require additional effort or financial investment are less popular (Ramsey et al. 2017). That is why policies should encourage consumers to purchase relatively cheap and easy-to-install water-saving mechanisms (March, Hernández, & Saurí, 2015). Finally, the incorporation of water-saving technologies may also be influenced by the perceived quality of water derived from the use of such devices. For instance, awareness campaigns should propagate information to reduce risk and perceptions of water produced by the desalination process as low quality (Villar-Navascués & Fragkou, 2021).

Analysis of the available DSM technology reveals that the existing methods and equipment are available not only for end users but also for water utilities. Understanding consumption behavior can lead to successful categorization based on the recognition of similarities in consumption patterns among consumers (Ioannou et al. 2021) and help forecast future trends, which is crucial for adequate demand management (De Oliveira et al., 2020). In the same line, applying data analytics and machine learning to data gathered from digital water meters may be a useful tool for gaining a better understanding of consumer behaviors, habits, and routines and, consequently, for creating more effective water conservation and demand management strategies (Rahim et al., 2021).

A field that is not yet commonly explored in the literature is Internet of Things (IoT) based methods, as only one of the 23 articles that explored water-saving technologies focused on this subject. The importance of studying such methods is related to the possibility of monitoring household appliances via wireless systems, collecting data in a central database and using those data to intervene in the consumption behavior of households (Edirisinghe & Pathirana, 2021).

Interestingly, in this review, a considerable number of articles that examined water-saving technologies focused on rainwater harvesting systems (Moy, 2012; Hunt & Rogers, 2014; Ramsey et al., 2017; Radonic, 2019). In Australia, Asia and Europe, rainwater collection systems are increasingly connected to indoor non-potable end uses, such as toilet flushing and laundry (Moy, 2012; Hunt & Rogers, 2014; Ramsey et al., 2017), while in the United States, rainwater tanks are promoted and used primarily for outdoor irrigation (Radonic, 2019).

Regarding rainwater harvesting, it is important to highlight that the installation of such systems does not necessarily result in a reduction in potable water use (Ramsey et al., 2017; Radonic, 2019). Additionally, the saving potential of rainwater tanks will not be realized and help reduce pressure on water sources if the sociocultural context is not recognized as the most influential determinant of consumption (Radonic, 2019).

2.3.2.3. Awareness (information and education)

Ten out of the 55 papers reviewed focused on public awareness as a factor in creating water-saving behaviors. The ways of creating awareness most explored in the literature were information dissemination (Hodges et al., 2020; Ong & Aral, 2021; Hunt & Shahab, 2021), educational campaigns (Lowe et al., 2014; Ramsey et al., 2017; Quesnel

& Ajami, 2017), and benchmarks and feedback (Hunt & Rogers, 2014; Hoppin & Meshes 2022).

Although information and education were the most studied methods and are likely to be necessary, they were not sufficient components of governmental programs for behavioral change (Martínez-Espiñeira & García-Valiñas, 2013; Hunt & Shahab, 2021). This is because, a combination of factors is needed to promote water-saving behavior, such as restrictions and subsidies (March et al., 2015), available technologies (Hunt & Shahab, 2021; Shahangian et al., 2022), and sociodemographic and economic characteristics of the target population (Hunt & Shahab, 2021).

Educational campaigns that teach easy ways to conserve water may increase the feeling of self-efficacy, leading to recommendations for how the adoption of certain behaviors can make a difference (Lowe et al., 2014; Ramsey et al., 2017). Communication and knowledge create awareness and induce individuals to act more responsibly by developing the personal need to act correctly (Hunt & Shahab, 2021).

There are different forms of providing information in this context. One is through news media, which was proven to be an efficient mechanism for reducing residential water use at the fastest possible rate (Quesnel & Ajami, 2017) as well as a potential way to encourage water-conservation behaviors by demonstrating that the government had invested in improving water security (Ramsey et al., 2017). Information dissemination through social media was another form with the potential to be an effective approach to change the use behaviors of household water consumers. The literature suggests that such communication is valued by people because it reduces their knowledge deficit and increases conservation behaviors (Lowe et al., 2014).

Awareness campaigns should regularly revise their scope and their channels of diffusion to guarantee their efficiency and to include water-saving innovations (March et al., 2015; Wang & Dong, 2017). Also, water awareness campaigns could benefit from more accurate knowledge of the habits of water use in targeted areas (March et al., 2015). Such knowledge includes information on both the success of past awareness campaign messages on different users and the evolution of water use habits.

2.3.2.4. Socioeconomic and demographic factors

For many years, these were the most explored factors in the literature since they have been shown to be some of the most significant in shaping household water consumption behavior (Damodaran, 2011; March, Perarnau, & Saurí, 2012).

Nevertheless, in more recent years, studies have shown that these factors alone are inconsistent in predicting environmental behaviors; thus, they have been used mainly to segment information, such as creating clusters (i.e., gathering households/inhabitants with similar characteristics) and investigating similar consumption patterns within such clusters (Wolters, 2014; Ibrahim et al., 2018; Villar-Navascués & Pérez-Morales, 2018; Rodonic, 2019; Sousa & Fouto, 2019; Ibrahim et al., 2021; Ito et al., 2021; Kumar, Sharma, Tabhani, & Otaki, 2021; Sousa, Teixeira, & Fouto, 2022). In the present literature review, socioeconomic and demographic factors were the main topic in only 8 of the 55 articles; however, variables associated with these factors were present in more than half of the studies read for this review (33 out of 55).

Socioeconomic and demographic factors are commonly used in models in studies of policies and other governmental actions toward water saving (Mini, Hogue, & Pincetl, 2014; Yuan, Wei, Pan, & Jil, 2014; Brelsford & Abbott, 2017; Biswas & Gangwar, 2021). This is mostly because understanding different behaviors among diverse sociodemographic groups provides opportunities for targeted interventions to enhance water conservation (Wolters, 2014; Wang & Dong, 2017).

March et al. (2012) and Rees et al. (2020) included a social factor that was not often considered in the articles analyzed but seems to be relevant: immigration. Consumption behaviors for immigrants seems to be in line with characteristics that are usually explained by three features from economic, sociodemographic, and cultural dimensions: low income, high-density habitation, and religious practices (March et al., 2012; Ahmad & Daura, 2019; Rees et al., 2020). Some studies showed that cultural domains explain environmental perspectives better than demographic factors, influencing effective and cognitive judgments about water issues (Larson et al., 2011).

The differences in economic characteristics among countries and their responses to water shortages are also important but have not been extensively explored in the literature. There are differences in the trends of water consumption between developed and developing nations, thereby implying a need for separate prospects of end-use results in these countries (Abu-Bakar et al., 2021). For instance, some authors have identified a declining trend in household water consumption in developed counties (March et al., 2012; Saurí, 2020), while in developing countries, especially those going through the urbanization process, per capita water consumption has increased in recent years (Damodaran, 2011; Ibrahim et al., 2021; Ito et al., 2021). Additionally, there are some particularities in developing countries, such as many people with no access to piped water, people living in slums (Ibrahim et al., 2021) and high levels of water lost in distribution, that could interfere with reduced water use and water consumption. The predominance of studies focusing on developed countries, evidenced in our descriptive analysis, has previously been criticized by Koop et al. (2019), who claimed that although most studies in the literature have been undertaken in developed countries experiencing water stress, water scarcity is clearly a problematic issue in many other parts of the world.

2.3.2.5. Water availability context

The context of water availability was the main object of 7 out of the 55 papers reviewed, a low number considering that scarcity events are becoming a more frequent problem. This evidence supports Vallès-Casas et Al's (2017) conclusions that the effects of contingent situations, such as drought episodes, remain less explored in the literature than other factors that influence household water consumption.

Although the relation between droughts and water-saving attitudes was not a "hot topic", studies that focused on understanding this subject evidenced that the water scarcity context induced people to incorporate water-saving habits (Bernardo et al., 2015; Beal et al., 2016; Wang & Dong, 2017; Sousa & Fouto, 2019; Stone & Johnson, 2022) Developing research on this topic is crucial to help understand the relation of drought and other factors that influence such habits and to identify the adopted behaviors to gather evidence that can be used in water-saving actions and policies.

The literature indicates that there are preferred actions and behaviors regarding reducing water use in a water scarcity context (Lindsay & Supski, 2017; Wang & Dong, 2017), such those related to outdoor water uses, including swimming pools and watering gardens. That is why, as Wang and Dong (2017) concluded, the outdoors is becoming an important place for people to implement water-saving practices.

The experience of drought was reported as a factor that changed consumer behavior even after a drought was over (Bernardo et al., 2015; Beal et al., 2016; Wang & Dong, 2017; Sousa, Teixeira, & Fouto, 2022; Stone & Johnson, 2022). This means that during water scarcity periods, people incorporate new habits that remain even when the dry periods end. Nevertheless, behavior and attitudes are not permanent and can change based on new information and experiences (Mankad et al., 2019).

Although it seems to be common sense that water conservation is important and is everyone's responsibility, water conservation attitudes and behaviors differ significantly in different locations, depending on the water context: inhabitants of locations that more frequently struggle with water scarcity tended to be more willing to conserve water (Rule et al., 2021). In other words, one may say that people living in drought-prone regions perceive more pressure to conserve water and try to conserve water wherever they can.

Finally, regarding other factors that, with water scarcity, shape water use behavior, Shahangian et al. (2022) identified a perception of a link between water scarcity and health and concluded that perceived severity derived from water scarcity-related health problems.

2.3.2.6. Policies

Policy-driven factors were the main topic in only 6 out of the 55 articles reviewed; however, they were also present in the other 19 studies. Recently, both water suppliers and public authorities have focused on demand-side water policies as a preferred alternative to supply-side initiatives (Martínez-Espiñeira & García-Valiñas, 2013). Such polices include public outreach, free waterwise landscaping consultation, tax rebates for waterwise landscaping, subsidized technologies for recycling wastewater, increasing awareness, and economic incentives, such as subsidies, fines for wasting water and tariff changes (Wang & Dong, 2017, Sousa & Fouto, 2019). It may also include reductions in water supply duration, an action that can have adverse effects, such as the creation of a scarcity mindset that leads people to be less likely to engage in water conservation behaviors (Ramsey et al., 2017). Nevertheless, in this second case, police-makers must have in mind that reductions in water consumption because of water supply restrictions tend to decrease over time (Tsuda, Nishida, & Irie, 2014).

Policies based on economic instruments have been shown to be effective in some cases reported in the literature (Lucas & Cordery, 2019; Stone & Johnson, 2022). On the other hand, other authors have claimed that economic incentives may have adverse results, such as problems of equity and fairness in the social effectiveness of economic measures (March et al., 2015) and may be poorly chosen by governments that are concerned about electoral cycles (Grover & Lucinda, 2021).

The literature has shown that mandatory and punitive policies may be more effective than policies such as voluntary watering restrictions. This finding has been reported for both indoor and outdoor water consumption reduction (Mini et al., 2014; Wang & Dong, 2017; Stone & Johnson, 2022). Nevertheless, programs aiming to encourage households to take these voluntary actions may succeed, as mentioned before, depending on perceived susceptibility and perceived severity.

Socioeconomic and demographic factors are commonly addressed in studies focusing on water-saving policies (Wang & Dong, 2017, Martínez-Espiñeira & García-Valiñas, 2013). They are important variables since understanding the differences in behavior among different sociodemographic groups allows targeted interventions (Wang & Dong, 2017). More commonly, the literature reports that higher-income families are more willing to support costly water-saving policies (Wang & Dong, 2017) and show larger reductions, probably because there is a greater margin for reducing consumption since they may use water for less essential activities (Sousa & Fouto, 2019). Additionally, low-income people who live in slums commonly do not have access to piped water and, therefore, may not respond to economic incentives (Ibrahim et al., 2021) or even other kinds of policies.

Brelsford and Abbott (2017) pointed out a difficulty in distinguishing policy-driven water consumption changes from changes driven by broader technological or demographic trends; they commented that, since governments often implement different water-focused policies simultaneously, and since such policies usually emerge during periods of social, technological, and demographic change, it is difficult to tell them apart. Additionally, DSM policies work better when decentralized (Abu-Bakar et al., 2021), meaning that the participation of different stakeholders, such as governments and households, regulators, and firms, is rather relevant. Understanding the dynamics of water conservation behaviors and consumption is helpful when formulating such policies (Ramsey et al., 2017).

Finally, water consumption reduction policies have some limitations. Apolitical approaches may be preferable for some populations (Mankad et al., 2019), considering that water scarcity is an issue that will also affect future generations and thus must be addressed throughout future years, which may not happen if policies are determined by electoral cycles (Grover & Lucinda, 2021).

2.3.3 Proposed framework

As indicated by the diversity of themes addressed in our literature review, understanding what shapes water conservation behaviors is rather complex. Additionally, the factors that shape water consumption are considerably mingled, as our analysis shows.

That is why, when aiming at water DSM, one must consider the diversity of factors that may influence water consumption behavior. Based on the present literature review, we developed an integrated framework (Figure 2.6), which aggregates our main findings on how different kinds of factors interconnect and influence household water consumption.

Behavioral factors are at the center of the framework, not only because they are the most studied topic in the studies in this review but also because they are directly or indirectly influenced by other factors. They represent behavioral determinants, which are those that better explain, based on the evidence from the articles reviewed, the actions and behaviors derived from stimuli for water saving.

The adoption of water-saving technologies is related to behavioral factors, as their use depends on the perception of the individual that such technology will contribute to conserving resources and will not impact the well-being of the individual (Mankad et al., 2019; Edirisinghe & Pathirana, 2021). They are also related to polices since those may be designed based on the available technologies.

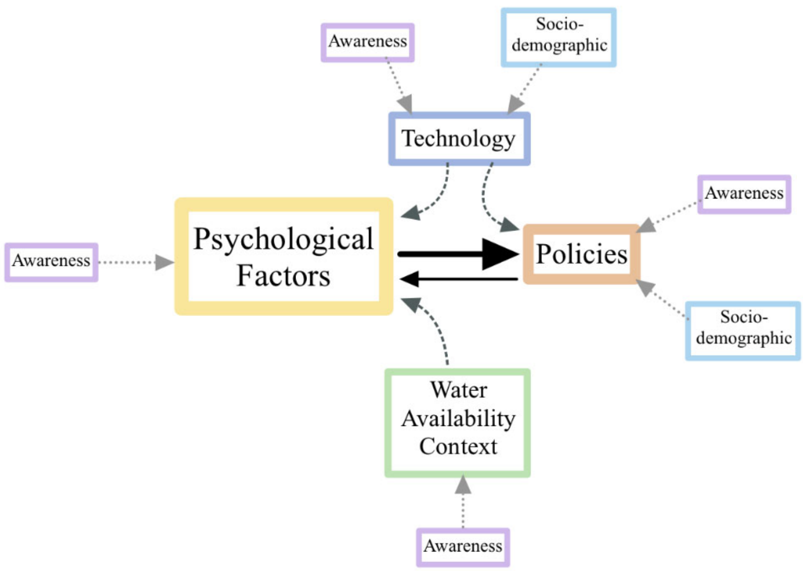
The literature also shows that the water availability context influences people to incorporate water-saving behavior (Wang & Dong, 2017; Stone & Johnson, 2022; Sousa et al., 2022). This happens because people feel the seriousness of the situation and generally understand that they are part of the problem as well as part of the solution (Gilbertson et al., 2011), and that is why, in our framework, the context influences psychological factors.

Although a limited number of studies focused specifically on awareness, including information and educational campaigns, we may infer from the reviewed articles that this subject is quite relevant for DSM. That is why, in our proposed framework, awareness impacts technology, water context, behavioral factors, and policies. First, information is crucial for people to understand the benefits of implementing new technologies and for overcoming preconceptions (Mankad et al., 2019; Shahangian et al., 2022). Second, awareness of the severity of droughts and the importance of action to overcome the situation can influence people's perception of the need to conserve (Gilbertson et al., 2011). Third, awareness induces individuals to act more responsibly by developing the personal need to act correctly (Lowe et al., 2014; Ramsey et al., 2017; Gómez-Llanos, Durán-Barroso, & Robina-Ramírez, 2020). Finally, information and education are needed to guarantee the efficiency of policies and to include innovations (Wang & Dong, 2017).

Socioeconomic and demographic factors may not be the most analyzed topics but are present as variables in almost half of the papers analyzed for this review. Although alone they are inconsistent in predicting environmental behaviors (Wolters, 2014), they assist in the understanding, for instance, of the adoption of technologies (Martínez-Espiñeira & García-Valiñas, 2013; Ramsey et al., 2017) and the acceptance of policies (Martínez-Espiñeira & García-Valiñas, 2013; Brelsford & Abbott, 2017; Wang & Dong, 2017; Sousa & Fouto, 2019).

Finally, there is a large body of studies on water-saving policies since demand-side water policies have been used recently by many water suppliers and public authorities (Martínez-Espiñeira & García-Valiñas, 2013), showing the importance of this topic and justifying the position of "Policies" in our framework. The framework also indicates that the understanding of the dynamics of water-conservation behaviors is helpful for the design of such policies (Ramsey et al., 2017), and that these polices are influenced by the level and frequency of awareness as well as socio-demographic factors.

Figure 2.6 – The relations of drivers that influence household water consumption behaviours



2.4 CONCLUSIONS

To comprehend household water consumption behaviors, we must consider a set of factors that this research aims to clarify: behavioral factors, available technologies, awareness, sociodemographic and economic features, water availability context and applied policies. The relation of these factors is identified in this review by a framework that aims to support future research as well as public policy design. It may not be a wise strategy to analyze each topic separately, as their relation is what determines water consumption behavior. In other words, overlooking the connections among the factors may result in poor research as well as inefficient policies. However, no research was found in the literature, including all six factors in their scope.

Overall, we conclude that all the factors analyzed somehow influence people's perceptions. The water availability context, existing technologies and policies implemented help build these perceptions, and these factors depend on socioeconomic and demographic characteristics as well as on people's awareness of the water context and the consequences of their own actions for water availability. To rightly shape people's water consumption behavior, it is necessary to analyze those determinants and create a policy that fits properly. This is a permanent exercise that requires constant evaluation of possible changes in such factors as well as communication.

Finally, this work highlights the importance in exploring the differences in the DSM from the country-of-origin perspective and points out that the literature still lacks studies of water consumption behavior in developing countries, where water scarcity is becoming a frequent problem. This review points out that exploring this matter is urgent. Understanding the specifics of each of the explored factors in different regions will enable the design of more efficient policies and the achievement of SDG 6. Thus, it is necessary to encourage and conduct studies in different countries, to provide guidelines for and insights into how to face the problem. Cooperation among developed and developing countries is a way to achieve this sustainable development goal.

3. OWNERSHIP IN TIMES OF WATER SCARCITY: ARE INHABITANTS SUPPLIED BY PRIVATE UTILITIES SAVING LESS WATER?[2]

Abstract: There is currently a call for public attention concerning the problem of water resources, and demand-side management has shown to be a way to decrease water consumption being implemented in many locations. In Brazil, where water scarcity is also an issue, in 2020 a new regulatory framework pushes water utilities privatization. In this context, it is relevant to understand if and to what extent the increase in the relevance of private companies in the sanitation market influences residential water saving attitudes. With that in mind, we held a hierarchical linear model with three levels (HLM3), using data of per capita water consumption of 858 Brazilian municipalities, from 2002 to 2019, and verified that, in average, inhabitants living in municipalities where private companies operate consume less water than inhabitants supplied by public companies. Increase in tariff prices due to privatization may be an explanation to such results, but this is not a consensus in the literature. Nevertheless, the results indicate the need of state-owned water providers, who are responsible for supplying more than 80% of the Brazilian population, to review their policies in water demand management, to decrease water consumption, using informational campaigns, encouraging voluntary saving behavior, and adopting economic incentives as well.

Keywords: ownership, water consumption, water saving.

3.1 INTRODUCTION

Nowadays, several cities around the world struggle to manage water resources in the face of population increases, consumer demand for water-intensive services, and increasing costs of developing new supplies (Olmstead & Stavins, 2009). Brazilian cities are not exceptions. Brazil, despite having a great amount of freshwater, has recently suffered water shortage events and, hence, many major reservoirs in the country have reached low capacity and many cities face imminent water rationing (Getirana et al., 2021).

[2] Co-author: Nuno M. M. D. Fouto. A first version of this article was presented at the Efficient 2023 Conference - IWA, in Bordeaux, France, in September/2023, during the poster section. At the event, it was awarded as the best poster presentation (Congress Proceedings available at: https://efficient.webs.upv.es/proceedings/).

In 2020, a bill was passed by the Brazilian Congress, changing the water and sanitation (W&S) sector core characteristics. One expected consequence of this bill is the increase of privatizations of water utilities in the country. Privatization of water services may be considered mostly in three possible scenarios: (*i*) municipalities with low coverage, where financial resources are needed for the expansion of the infrastructure; (*ii*) operations with low efficiency, where there should be investments in more efficient equipment; and (*iii*) places where there is a need to trigger and sustain systematic performance improvements (Beecher & Kalmbach, 2013; Homsy & Warner, 2020; Tourino, Santos, Pinto, & Camanho, 2022).

The importance of ownership structure in water service provision has been widely discussed in the recent literature (P. Carvalho, Pedro, & Cunha Marques., 2015; Pazzi, Tortosa-Ausina, Duygun, & Zambelli, 2016; Wait & Petrie, 2017; Hellwig & Polk, 2021), but little importance has been given on how ownership may affect water consumption. In the country's context of water scarcity and privatizing incentive, it is worthwhile understanding if and to what extent the increase on the private sanitation market influences residential water saving attitudes. Hence, this paper tries to fill this gap, by answering the following question: in Brazil, inhabitants supplied by private utilities have different water consumption behavior than those supplied by public companies?

The article is organized as follows. In Section 2 (3.2), we review the literature on water price, water consumption behavior, and ownership of water provision. In Section 3 (3.3), we describe the Brazilian water and sanitation history and regulatory context. In Section 4 (3.4), we describe the methodology used in our quantitative analysis. In Section 5 (3.5), we analyze the findings of the quantitative analysis and discuss the results. The last section draws conclusions, implications and suggests future lines of research.

3.2 LITERATURE REVIEW

3.2.1 Water market and price

Water supply systems have three special features: (*i*) they are exceptionally capital-intensive and asset-specific, (*ii*) the associated fixed costs account for most operating expenses, and (*iii*) the water infrastructure is a natural monopoly (Peda, Grossi, & Link, 2013; P. Carvalho et al.., 2015). As a natural monopoly, it is difficult to turn the water supply industry into a fully competitive market, since the nature of costs does not permit the duplication of the network as well as the fragmentation of the market would limit the economies of scale (Pérard, 2009).

Usually, water prices include costs of acquisition, treatment, and delivery of water (Zhang, González Rivas, Grant, Warner, 2022), but studies indicate that the price charged for water in urban centers is below the optimal price (Renzetti, 1992, Timmins, 2002; Arbues & Barberan, 2004). One reason for that is that water price is generally not determined by the market, due to this natural monopoly characteristic, and consequently does not reflect its scarcity (Olmstead, 2010). Moreover, without the existence of a market, per se, water prices end up not automatically responding to changes in supply.

3.2.2 Water consumption behavior

As access to new water sources becomes more difficult, demand side-management (DSM) has become increasingly important. DSM is a managerial approach that aims at meeting the demand for water through the application measures and incentives to achieve fair and effective utilization of water (Al-Zahrani et al., 2013). Understanding the drivers of water consumption is a crucial topic of research and must be considered in water related policies and managerial actions. A row of factors shapes residential water availability context, awareness, social demographic characteristics, and policies (Sousa & Fouto, 2019).

For instance, managers may choose pricing strategies as effective water conservation policy tools to reduce consumption (Sousa & Fouto, 2019; Homsy & Warner, 2020), especially in periods of scarcity. This is because economic factors, such as pricing strategies, influence people's perceptions of water consumption and its impacts. That may be one of the reasons why the influence of price on water consumption is well explored in the literature (Dalhuisen Florax, De Groot, & Nijkamp, 2003; Stavins, 2005; Olmstead, Hanemann, & Stavins, 2007; Vallès-Casas et al., 2017; Sousa & Fouto, 2019).

3.2.3 Ownership structure

Water and sanitation utilities face many challenges, including ensuring universal access to water and sanitation services with an acceptable quality in a context of limited availability of water (Barbosa & Brusca, 2015). Yet, they can be key partners in local government sustainability efforts, as water resource management is linked to equity, economic development, and environmental protection (Homsy & Warner, 2020).

The importance of ownership structure in water service provision has been widely discussed in the literature. Although several topics have been included in the ownership analysis – such as effectiveness, equitability, and sustainability – research focus mostly on pricing (Barbosa & Brusca, 2015, Wait & Petrie, 2017; Hellwig & Polk, 2021; Zhang et al., 2022) and efficiency (Braadbaart, 2002; Renzetti & Dupont, 2004; Pazzi et al., 2016). Nevertheless, despite the high number of studies, many of them do not provide definitive conclusions concerning the superiority of water utilities from the ownership perspective (P. Carvalho et al., 2015).

Ownership has not been widely studied in recent literature as a factor that influences behaviors regarding water consumption, although it may be a factor. To the best of the authors' knowledge, only Kallis, Ray, Fulton, & McMahon (2010)'s study adopted such focus, presenting insights from a survey conducted in California (US), concluding that privatizations and their associated reforms can reduce conservation potential by exhausting the willingness of users to cooperate on water saving.

3.3 SANITATION IN BRAZIL

In 2021, more than 30 million people in Brazil did not have access to clean water, as only 84.2% of the population were supplied with piped water, as reported in the Brazilian National Sanitation Information System[3] (SNIS). The water sector is still characterized by strong differences in the access to services between the urban and rural regions (P. Carvalho et al., 2015). Moreover, the W&S sector in the country presents great inequality: while some municipalities have overcome universalization issues, there is a huge number of cities that require major advances to mitigate the effects of the accumulated social debt (Britto et al., 2012). For instance, municipalities of the North and Northeast regions of Brazil have, on average, worse performance in the sector, compared to cities in the South and Southeast regions, as data from SNIS shows.

The main features of the Brazilian W&S were developed in the 1970s, through the implementation of the National Basic Sanitation Plan ("Plano Nacional de Saneamento –

[3] Available on: http://app4.mdr.gov.br/serieHistorica/

Planasa", in Portuguese), when a new structural regimen was established for the sector (Heller, 2007). This plan led to the creation, in each Brazilian state, of a State Water Company, stimulating economies of scale through regional organization of the service providers (P. Carvalho et al., 2015), particularly in the fast-growing metropolitan areas (Seroa da Motta & Moreira, 2006), and encouraging municipalities to make long-term concessions to these firms in exchange for investments granted by a state-owned bank (Banco Nacional da Habitação, BNH; Seroa da Motta & Moreira, 2006). The National Basic Sanitation Plan had significant results: 15 years after its introduction, urban population with access to drinking water went from 50% to 87% (P. Carvalho et al., 2015). Nevertheless, with the bankruptcy of BNH, in 1982, the plan lost its strength and the development of the sector slowed down (Margulies, 2018).

In February 1995, a new act was implemented, challenging state firms' monopoly (Seroa da Motta & Moreira, 2006). As a result, there was an increase in private sector participation in the industry, once municipalities conceded water and sanitation services to private companies seeking to ensure an expansion of their services (P. Carvalho et al., 2015).

Due to this past, water and sanitation services' (WSS) operators in Brazil, in a simplified way, belong to one of the following categorizations: (*i*) local public entities (directly administered by the municipalities); (*ii*) local or regional private entities; and (*iii*) regional public entities (Seroa da Motta & Moreira, 2006; Tourino et al., 2022). In 2022, over 90% of the 5,570 Brazilian municipalities were supplied by public utilities (state or municipal), in which 81.6% of the Brazilian population lived. Private companies were responsible for providing water in nearly 450 municipalities (8.1%), supplying over 39 million people (18.4% of total Brazilian population). Despite this reduced participation in the market, private companies have gained prominence, given the State's low investment capacity (Tourino et al., 2022).

In 2020, a new regulatory framework for sanitation was introduced in Brazil, bringing significant changes to water and sanitation provision in the country. Some of the most impacting changes are: (*i*) setting mandatory goals for universal access of water and sanitation services; (*ii*) encouraging regionalized provision of the services; and (*iii*) centralizing regulation, by designating the role of general guideline development for the national water regulator. In what concerns utilities ownership, this new regulatory framework encourages privatizations because of: (*i*) greater legal certainty for the privatization of state-owned companies; (*ii*) strengthening competition in the market, by prohibiting the formalization of contracts between municipalities and state companies without bidding process; and (*iii*) making mandatory to organizing bidding processes when conceding municipal WSS.

3.4 METHOD

3.4.1 Model framework

To verify if residents supplied by private water utilities have different water consumption behavior from those supplied by public companies, a multilevel model framework was used, due to the hierarchical characteristics of the data. The main advantage of multilevel models over traditional regression models is the consideration of the natural nesting of data, allowing researchers to analyze individual heterogeneities between groups in which these individuals belong to, enabling the specification of random effects in each level of analysis (Santos, Fávero, & Distádio, 2016; Hair & Fávero, 2019).

In our study, we proposed a hierarchical linear model with three levels (HLM3), For the first level, we consider the year; the second level of the model is the municipality itself; and the third level is the federative unit in which the municipality is located.

3.4.2 Data source and variables

For this study, we used data from SNIS, Brazil's official database for municipalities' WSS operational and financial information. Data from SNIS may present some inconsistency, once, although it is the governmental official source, information is self-declared by municipalities' administration and is not revised by the federal government or audited by a third party. That is why we considered it important to revise and analyze the collected data, before running the model. The steps used for the evaluation and refining of the collected data is summarized on Table 3.1 and the aim was to improve the reliability of the database. After the treatment, our database was composed of information of 858 Brazilian municipalities, located in 27 federal units (states), from 2002 to 2019.

Table 3.1 – Steps of the evaluation of the collected data from SNIS

Problem	Justification	Solution
Reliability of information reported by small municipalities	Small municipalities usually have no measuring systems (or inaccurate ones), as well as little know-how and small staff to guarantee refined information regarding sanitation.	Municipalities with less than 10,000 inhabitants were excluded from the database.
Small period of operation	In our understanding, recently established operations must not be included in the model, since infrastructure improvements and new habits establishment by the population take time.	To be conservative, we considered a minimum of 5 years operation of a same utility owner, for each studied municipality.
Inconsistent data	In some cases, the % of households with water supply and non-revenue water indicator of a municipality varied considerably from year to year. Such variation is not plausible, since implementations of sanitation infrastructure takes time and, thus, the number of people served by water or water loss index may not vary considerably from one year to another.	We removed data from municipalities where indicators, such as urban water service index, varied considerably from year to year. To keep a considerable amount of municipality data in our evaluation, we settled the following criteria when analyzing inconsistencies: if there was inconsistent data for a municipality only in the first and/or in the last year of the provided information, we removed information from only those years. If the inconsistent data was present in only one year, but not the first or the last, we replaced the inconsistent information with the average from the data of the adjacent years.

As the dependent variable, we considered the annual average per capita water consumption (l/inhab.year). The use of per capita data was chosen seeking to normalize the consumption by the population, given the uneven residential features in each municipality (Vallès-Casas, March, & Saurí, 2017).

The considered explanatory municipal variables, that vary through the years, were urban water service index, which indicates the percentage of urban population in each municipality with access to drinking water, and the non-revenue water (NRW) index, which accounts for the share of water that is extracted and treated but lost in the distribution process due to leaks or that is not billed due to uncorrected measurement or unauthorized use. The urban water service index was considered since, as Magnusson (2004) points out, the willingness to respond to demand management is reduced with improved access to water. The NRW index was chosen, because illegal residential connection to the network is still a common practice in vulnerable areas (mainly slums and settlement areas; Marques & Saraiva, 2017; Sampaio & Sampaio, 2020; De Santi, Cetrulo, & Malheiros, 2021) and may as also less susceptible to water conservation incentives (Sousa & Fouto, 2019). Finally, as control municipal variable, also that varies through the years, we used municipal per capita Gross Domestic Product (GDP), collected from the Brazilian Institute of Geography and Statistics (Instituto Brasileiro de Geografia e Estatística – IBGE, in Portuguese) database. It was used as a control variable, considered as a proxy for local income, since income has proven to be a significant factor in shaping water consumption (Sousa & Fouto, 2019; Sousa et al., 2022).

As explanatory variable at level 2, we considered ownership, which was reported as a dummy, being direct administration, municipal administration, state companies, and mixed capital companies with public administration considered as "state owned" (0), while private companies were classified as "private" (1).

Table 3.2 shows the descriptive statistics of the variables used in this study.

Table 3.2 – Variables characteristics and key descriptive statistics

Indicator	Type	Unity	Variable	Mean	Median	Min	Max.
Average per capita annual water consumption	Quantitative	l/ (inhabitant X year)	X_1 (dependent variable)	139.4	132.80	37.35	363.17
Ownership	Qualitative	0 = state-owned 1 = private	Y_1 (explanatory variable)	-	-	-	-
Urban water service index	Quantitative	%	Y_2 (explanatory variable)	92.71	99.80	8.30	100.00
NRW index	Quantitative	%	Y_3 (explanatory variable)	39.67	38.33	4.89	96.15
Annual per capita GDP	Quantitative	R$	Y_4 (control variable)	21,446	15,734	1,181	42,8020

3.4.3 Model design

We used a "step-up strategy" for our multilevel model design, in line with Raudenbush and Bryk (2002). The first step in our model design is to develop a null model, only based on the grouping process, i.e., in which we do not include explanatory variables. The null model, in which water consumption is determined by a global average, plus an error term corresponding to the group of federative unit μ_{00k}, municipalities τ_{0jk}, and the residual idiosyncratic error εijk, is as follows (Equation 3.1):

$$Consumption_{tjk} = \gamma_{000} + \mu_{00k} + \tau_{0jk} + \varepsilon_{ijk} \quad (3.1)$$

We, then, included the level 1 variable (year) to identify if there is a linear trend of water consumption through the years (Equation 3.2). The evolution of average water consumption through the years evidences a linear behavior of consumption over time, indicating it is plausible to include the variable year, with linear specification, at level 1 of the model.

$$Consumption_{tjk} = \gamma_{000} + \gamma_{100}.year_{jk} + \mu_{00k} + \tau_{0jk} + \varepsilon_{ijk} \quad (3.2)$$

Thirdly, we included the second level variable "ownership" (dummy) in the model (Equation 3.3), to verify if this characteristic of the operator explains the variation on annual average water consumption among municipalities. The linear trend model with random intercept and slope and the variable "ownership" expression can be written as follows:

$$\begin{aligned} Consumption_{tjk} \\ &= \gamma_{000} + \gamma_{100}.year_{jk} + \gamma_{010}.ownership_{jk} \\ &+ \gamma_{110}.ownership_{jk}.year_{jk} + \mu_{00k} + \mu_{10k}.year_{jk} \\ &+ \tau_{0jk} + \tau_{1jk}.year_{jk} + \varepsilon_{ijk} \end{aligned} \quad (3.3)$$

Finally, we included the other variables: urban water service index, non-revenue water index and per capita GDP (Equation 3.4). The complete model can be written as follows:

$$\begin{aligned} Consumption_{tjk} \\ &= \gamma_{000} + \gamma_{100}.year_{jk} + \gamma_{010}.gdp_{jk} + \gamma_{010}.service\_index_{jk} \\ &+ +\gamma_{010}.NRW_{jk} + \gamma_{010}.ownership_{jk} \\ &+ \gamma_{110}.ownership_{jk}.year_{jk} + \gamma_{110}.service\_index_{jk}.year_{jk} \\ &+ \gamma_{110}.NRW_{jk}.year_{jk} + \gamma_{110}.gdp_{jk}.year_{jk} + \mu_{00k} \\ &+ \mu_{10k}.year_{jk} + \tau_{0jk} + \tau_{1jk}.year_{jk} + \varepsilon_{ijk} \end{aligned} \quad (3.4)$$

3.5 RESULTS AND DISCUSSION

Table 3.3 presents the estimation results of the complete model. These results indicate that, on average, users supplied by private utilities tend to consume less water than those supplied by state owned utilities. Also, they reveal that water service index, non-revenue water index and per capita GDP are also statistically significant to predict water per capita consumption, but while for water service index and non-revenue water the correlation with the dependent variable is negative, for per capita GDP, it is positive.

Table 3.3 – Estimation results of the random intercepts model

	Value	**Std. Error**	**DF**	**t-value**	**p-value**
Intercept	- 361.6275	80.34122	11500	- 4.50115	0.0000
Year	0.2877	0.03990	11500	7.20942	0.0000
Ownership	- 0.0069	0.00250	11500	- 2.73798	0.0062
Water service index	- 0.5178	0.02742	11500	- 18.88685	0.0000
NRW index	- 0.8639	0.02120	11500	- 40.74603	0.0000
Per capita GDP	0.0001	0.00002	11500	4.50722	0.0000
Variance decomposition					
Municipalities (τ0jk)	844.0637	42.912514	-	19.669407	0.000
Federative Unit (μ00k)	498.1030	155.652499	-	3.200097	0.001
Idiosyncratic error (εijk)	250.8808	3.311602	-	75.758122	0.000
Likelihood ratio test	-53397.67	-	9	-	-
Number of Observations			12,363		
Number of Groups	**UF**	27	**Municipalities**		858

The fact that, as shown in our analysis, residences supplied by private companies consume, on average, less water do not corroborate Kallis et al. (2010)'s findings, that privatizations and their associated reforms can reduce conservation potential. There are several potential explanations for such facts.

Several studies demonstrated that privately owned water utilities charge higher prices for water services (Martínez-Espiñeira et al., 2009; Beecher & Kalmbach, 2013; Wait & Petrie, 2017; Zhang et al., 2022), which could be a plausible explanation for the fact that inhabitants provided by private companies tend to consume less water. This is because the literature indicates that increasing prices is an effective tool in reducing water consumption (Gilbertson et al., 2011; Sebri, 2014; Sousa & Fouto, 2019; Homsy & Warner, 2020).

As stated before, in the literature a great focus was placed on pricing in studies regarding water utilities ownership. For instance, Zhang et. Al (2022), in a study of the 500 largest community water systems in the US, concluded that privately owned systems have higher annual bills, the same insights found by Beecher and Kalmbach (2013), when studying the Great Lakes region. In the same line, when studying the Brazilian water market, Barbosa & Brusca (2015) found that privately owned utilities charge higher prices, even when utilities are under local and regional regulatory agencies' price mechanisms. There is also evidence that relate privatization to price increase and to consumption reduction: Vallès-Casas et al. (2017)'s work evidenced that the sharp increase in the price of water in Spain, after the privatization of a regional supplier, led to record decreases in consumption (total, per capita and per meter).

Despite what the so far cited works show, relating ownership and water prices, it is worth noting that, as Marques and Simões (2020) put, private operators apply higher tariffs due to the stricter requirements that they must comply with, and, thus, higher prices are not associated with excessive profits. Additionally, García-Valiñas, González-Gómez, and Picazo-Tadeo (2013) point out that when water services are provided by state companies, especially municipal ones, costs might not be reported properly and are, therefore, not passed on in full to prices. Although those factors may be true, in the end, what matters to users is the price on their water bill, meaning that the final price charged is what is able to shape users' behavior concerning water consumption and saving.

One way for state-owned water utilities to promote water saving is through public policies which may have different focuses. For instance, the literature indicates that information and educational strategies are crucial to shape water consumption (Jethoo & Poonia, 2011; Lowe et al., 2014; Ramsey et al., 2017; Quesnel & Ajami, 2017). However, although information and education are likely to be necessary, they are not sufficient components of governmental programs for behavior change, since a combination of factors is needed to promote water-saving behavior (Martínez-Espiñeira & García-Valinas, 2013; March et al., 2015; Sousa & Fouto, 2019).

In what concerns water service index, in municipalities with higher service indexes people tend to consume less water, and this finding is in line with the literature (Ito et al., 2021). There are three plausible explanations for this result: first, low service indexes usually indicates that the municipality is short on resources to improve sanitation services (Sousa et al., 2019), including less resources for awareness programs on water saving actions. In the understanding of Ito et al. (2021), households using treated water may be able to implement strategies for coping with water scarcity as they may have high awareness of conserving water. Indeed, as Magnusson (2004) states, for long-term changes in water consumption behavior patterns, awareness and education must be part of the solution.

Second, in regions where service rates are lower, the level of non-revenue water (water that is lost during distribution, unauthorized consumption or under metered water due to metering inaccuracy) is higher, meaning information on per capita consumption may be over quantified. As Ibrahim et al. (2021) pointed out, in developing countries, a considerable part of population does not have access to piped water, meaning that they commonly do not pay for the consumed water and, thus, may not respond to economic incentives (Ibrahim et al., 2021), such as price increases. This may be considered a good explanation to why NRW index also has a negative and significant correlation to average per capita water consumption. Indeed, in Brazil's North and Northeast regions, the two with lower per capita GDP and lower water and sanitation service indexes, leakage indicators are quite elevated: these regions' non-revenue water rates are 46.2% and 51.2%, respectively (SNIS, 2022). In some Federative Units in the North region water losses are above 70% of the total produced water (SNIS, 2022), meaning that over 70% of the produced water is not billed, because is lost during distribution or because is consumed illegally.

Third, ownership correlates positively to services indexes, meaning that private owned water utilities usually have higher services indexes. For instance, in our database, private players' water service's mean, from 2002 to 2019, is around 96,2% while the mean for state-owned utilities is 91,5% (SNIS, 2022). This must be explained by the fact that water utilities with private participation are more efficient than those with no private intervention (P. Carvalho et al., 2015; Tourino et al., 2022).

One limitation of the present work relates to the impossibility to understand if the simple knowledge by the population on water utilities ownership influences water consumption behavior, disregarding the price charged for water. In that sense, a qualitative survey would be a suitable instrument to help overcome such limitations. Kallis et al. (2010), held a work in this way, surveying water users in California. The authors' survey included questions such as: (*i*) how users might respond if their provider required them to cut back on water use; (*ii*) whether users were aware of the state/private character of their water provider and (*iii*) if users thought that their responses would be influenced by whether their providers were the state or private companies.

3.6 CONCLUSION

Using a multilevel model framework, we demonstrated that, from 2002 to 2019, Brazilian inhabitants provided by private water utilities consumed, in average, less water than public water utilities. In times of climate changes and water availability uncertainties, and especially in areas of water stress, the level of water consumption should be considered among other determinants when choosing whether to concede water services. Also, the results presented in this study also indicate the need of state-owned water providers to review their policies in water demand management, to decrease water consumption, using informational campaigns, encouraging voluntary saving behavior, and adopting economic incentives as well. Considering that state-owned companies in the country are still responsible for providing water for nearly 80% of the Brazilian population, such actions are quite needed.

Future research should analyze water consumption in Brazil, in the upcoming years, when private participation is expected to be intensified. Also, a deep analysis using surveys may enrich the results of our study, since they may allow researchers to verify if the simple knowledge by the population on water utilities ownership influences water consumption behavior, disregarding billed water price.

4. DRIVERS OF NON-REVENUE WATER IN DEVELOPING COUNTRIES: A MULTILEVEL APPROACH FOR THE BRAZILIAN CASE[4]

Abstract: The growing pressure on water resource has led to an urgency in increasing efficiency in water supply, which includes minimizing water loss. Using a multilevel model framework, we identify the main drivers of non-revenue water in Brazil. Such identification is useful to elucidate the reasons why NRW increased in the past years in the country, as well as to help governments and water utilities' managers to take potential actions to reverse this scenario. Only four of the ten factors considered, chosen from information on the available literature, were statistically significant to explain NRW: population size, share of residential consumers, network length and ownership. Also, the kind of relation with water loss levels (positive or negative) differed in some cases from the findings in available studies, reinforcing the need to consider regional particularities when studying ways to reduce NRW and implementing public policies.

Keywords: Water loss; NRW; developing countries; action design; public policy.

4.1 INTRODUCTION

The growing pressure on water resources, which is accelerating due to climate change and increasing occurrence of extreme weather events, has led to an urgent need in increasing efficiency in water systems, which includes minimizing water loss (González-Gómez et al., 2012; Pillot, Catel, Renaud, Augeard, & Roux, 2016). Nevertheless, despite the uncertainties related to water availability in the future, water utilities still struggle with non-revenue water (NRW; Pillot et al., 2016; Amaral, Martins, & Dias*,* 2023; Beker & Kansal, 2023).

A greater part of the existing studies devoted to assessing performance in the water industry has focused on managerial performance, ignoring other dimensions of the management of water resources, such as sustainability (Sáez-Fernández*,* González-Gómez, & Picazo-Tadeo*,* 2011). Water loss reduction is an important part of sustainable water management, once it contributes to reduce the volume of water abstracted, as well

[4] Co-author: Nuno M. M. D. Fouto. Previous versions of this article were accepted to be presented in the XXVI Semead and in the XXV Engema, both events held in São Paulo, Brazil, in November/2023.

as other environmental associated impacts, such as those related to water treatment and distribution (Pillot et al., 2016). Additionally to the benefits of water conservation, reducing water loss may improve water service reliability and water quality (Liemberger & Wyatt, 2019; Arsesp, 2020).

Although a greater part of the produced water is devoted to agriculture, urban water management improvement is also relevant (González-Gómez et al., 2011), once urbanization is still an ongoing process, especially in developing countries (Ravallion, 2002; Wang, Liu, Liao, & Wei, 2021; Sikder et al., 2022). The analysis of urban water supply service performance has been the focus of a considerable number of studies, yet, such studies have mainly centered on developed countries, indicating a gap in the literature (Cetrulo, Ferreira, Marques, & Malheiros, 2020). Specifically in what regards NRW, there are few scientific studies on this topic that have focused on water loss control performance in developing countries (De Santi et al., 2021), where the waste of resources resulting from high NRW levels is considerable (Kingdom, Liemberger, & Marin, 2006; IFC, 2013; Margulies, 2018; De Santi et al., 2021). Given the scarcity of resources in developing regions, understanding the most significant drivers of NRW may help utilities and governments focus on the real problem and save resources when applying the corrective actions.

Brazil has been facing water scarcity in the last years, in different regions of the country (Sousa & Fouto, 2019; Getirana et al., 2021; Sousa et al., 2022). Yet, in Latin America and the Caribbean region, Brazil has the highest NRW level (De Santi et al., 2021). In the country, water loss in the last years has been growing, reaching the level of 40% of total produced water in 2021 (SNIS, 2022). That is why there is an urgency in implementing effective plans and actions focused on reducing this problem (Oliveira, Scazufca, & Sayon, 2022). Considering this scenario, this study seeks to identify the main drivers of non-revenue water in Brazil, presenting potential actions to reverse this scenario.

This paper is organized as follows. In Section 2 (4.2) we undertake a literature review, bringing definitions and insights related to NRW. In Section 3 (4.3), we define the hierarchical linear model used to estimate the drivers of water losses in Brazil. In the fourth section (4.4), we present the estimation results. A final section (4.5) brings the conclusions of the research work.

4.2 LITERATURE REVIEW

4.2.1 Water loss definition

Water loss in a system may be defined as total water input (produced and imported water) minus the invoiced water. It includes both real losses as well as apparent losses. The first relates to water that entered the water system but did not reach the final consumer, due to leaks in the distribution network or leakages in the reservoirs; this first type is an example of resource waste. The latter relates to the water that is not billed due to uncorrected measurement or unauthorized use; this volume may not be considered as waste, however it jeopardizes water utilities' revenue. Despite the differences between these two kinds, water losses have high implications, with significant repercussions on political, economic, social, technological, legal, and environmental aspects (Arsesp, 2020).

Reducing water losses is not just a technical issue. Some barriers to reduce losses are also related to the fact that water utilities, mostly the ones located in developing countries, often operate under a weak governance, with multiple political and economic constraints (Kingdom et al., 2006). The lack of incentives for management units, of awareness among users and of political willingness are also some causes of high levels of water loss in cities worldwide (Gonzaléz-Gómez et al., 2011).

The drivers of water losses and the actions implemented to minimize them are related to physical features (technical-operational characteristics of the water supply system), utility management qualities (including planning) and other factors specific to where the utility is located (Ferro, Lentini, Mercadier, Romero, 2014; Van den Berg, 2015; De Santi et al., 2021). There is no water distribution system with zero water loss; nevertheless, the more efficient the system, the lower NRW levels are (SNIS, 2022).

4.2.2 Implications of NRW

Utilities' operations must be guided by measures seeking to reduce NRW to as little as possible. This is because NRW represents a burden, both financial and environmental (Amaral et al., 2023), indicating a great source of inefficiency for water utilities (Alsharif, Feroz, Klemer, Raab, 2008).

Both real and apparent losses influence the financial performance of utilities as they implicate waste of resources spent on treatment and distribution, due to a water produced that does not become revenue. NRW damages water utilities' financial situation, implying lower income from billing and higher operating costs (González-Gómez et al., 2011). NRW high rates indicate several management problems, such as the neglect of a public good, unregulated hydrometers, infrastructure with little maintenance, as well as waste of electricity and other inputs applied in production (Margulies, 2018).

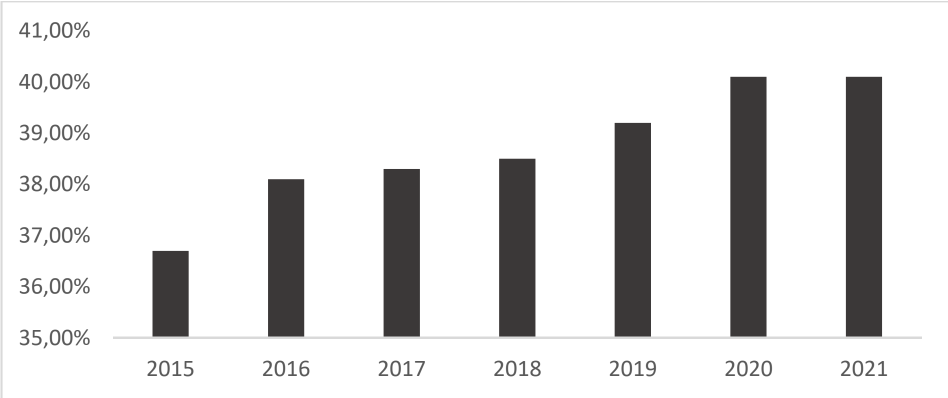
Reducing NRW contributes to water conservation and sustainability in urban areas. This is because real losses implicate in a waste of a natural and scarce resource as well as demand expansion in water redraw and expansion of water springs (Oliveira et al., 2022). Particularly in a context of climate change and water scarcity, water loss reduction emerges as a sustainability factor and is directly associated with the optimization of the use of a finite natural resource and restricted access (SNIS, 2022).

Finally, water leakages also imply the risk of drinking water being contaminated, by lowering pressure of the distribution network (González-Gómez et al., 2011; Oliveira et al., 2022). In this sense, besides being environmental and financial problems, water leakages may also represent a public health issue.

4.2.3 NRW in Brazil

In Brazil, water loss was not directly addressed by regulation up to recent years. The Federal Law No 8,987/1995 (*Lei n. 8.987*, February 13, 1995) – which determined the provision of an adequate and efficient water supply service – and the Federal Law No 11,445/2007 (*Lei n. 11.445*, January 5, 2007) – which determined water provision guidelines that included efficiency, sustainability, and reduction of waste of resources, among others – did not address, specifically, the water loss issue. Also, since the introduction of the Water National Plan (Planasa), in the 1970's, which prioritized the construction of water supply systems, rather than projects that would improve the overall efficiency of service providers, a scenario of excessive losses was created (P. Carvalho et al., 2015). This scenario still lasts in recent years: in the period of 2015 to 2021, physical water losses increased from year to year, reaching about 40% (Figure 4.1).

Figure 4.1 – Evolution of NWR in Brazil



Source: SNIS (2022)

Throughout the country, the values of NRW are quite distinct. Considering Brazil's five macro-regions, water loss rates vary from 36.2% (in the Midwest region) to 51.2% (in the North region). Considering the 27 federative units within the country, the lowest index is of 28.5% (in Goiás), while the highest reaches 74.6% (in Amapá; SNIS, 2022).

Some factors that may explain the high levels of NRW in Brazil, especially in some regions, are the scarcity of financial resources for the acquisition of leakage detection equipment and for infrastructure adequation, the low price of raw water, and the low diffusion of technology. The existence of a great part of population living in areas of social vulnerability (Marques & Saraiva, 2017; Margulies, 2018) additionally to the lack of educational campaigns (Sousa & Fouto, 2023) may also be listed as some of the barriers to overcome this problem, as well as the high political cost in attempting to reduce apparent losses due to unauthorized consumption (González-Gómez et al., 2012).

The high levels of NRW and its increasing trend over the past years in the country highlight a problem that needs to be addressed with some urgency. In 2020, Federal Law n. 14,026/2020 (*Lei n. 14.026*, June 15, 2020) established that water supply concession contracts must foresee gradual water loss reduction goals, but without determining which should be such goals. More recently, in 2023, a bill passed in the Brazilian Congress, determining that water utilities must take actions to correct network failures to prevent leaks and losses, as well as to increase the efficiency of the distribution system and monitor the water supply network to curb irregular connections. This bill, however, is still not valid.

Particularities within the country, like the different types of operators or the demographic characteristics in the region of operation (i.e., densely populated regions, restricted water supplies, among others), must be considered when designing public policies to reduce NRW in Brazil. Differences in the context in which the utility is operating make a "*one size fits all*" benchmark for NRW levels not very useful (Van den Berg, 2015), meaning that Brazil should not rely on other countries' experiences, specially developed countries.

4.3 METHODOLOGY

4.3.2 Factors affecting NRW indexes in Brazil

There are few studies that evaluate the drivers of water loss. The topic of NRW is usually analyzed in studies regarding water utilities efficiency, being one of the measured variables in such work. Table 4.1 summarizes some recent work that evaluates water losses.

Table 4.1 – Chronological summary of previous literature regarding water loss analysis

Authors	Region	Objective	Method	Variables
Alsharif et al., 2008	Palestine	Assess the relative efficiencies of water supply systems and to establish benchmarks	Data envelopment analysis (DEA)	• Raw water cost • Energy cost • Maintenance and other expenses • Wages
Picazo-Tadeo et al., 2009	Spain	Assess technical efficiency in water utilities	Data envelopment analysis (DEA)	• Delivery network length • Sewer network • Number of workers • Operational costs
González -Gómez et al., 2012	Spain	Identify water loss drivers	Simple Weighted least square regression	• Type of abduction system • Treatment level applied to raw water • Age of the distribution system • Costs X revenue ratio • Ownership • Urban center • Number of municipalities supplied • Pop. Growth rate • Network length • Political Ideology
Adams & Lutz Ley, 2012	Mexico	Identify the factors related to water losses	Pooled Ordinary least squares (OLS) regression	• Production cost • Charged price • Ownership • Population size • Inhabitants per connection • GDP • Historical average temperature • Average annual precipitation • Coverage of metering
Van den Berg, 2015	Cross country	Assess the main drivers of water losses	Ordinary	• Population density • Urban center • Cost of energy

Authors	Region	Objective	Method	Variables
			least squares (OLS) regression	• Universal coverage • Net revenue • Size of staff • Wage rate
Ociepa, Mrowiec, & Deska, 2019	Poland	Analyze and evaluate the amount of water losses in supply systems exposed to mining activities	Benchmark indexes and indices calculation	• Water supplied to the network • Network length, quantity, and length of water • Supply connections, material and age structure of the network, the number of recipients, average • Pressure in the tested network • Number of failures in individual years
Villegas et al., 2019	UK	Estimate the bias-corrected efficiency scores and identify the environmental variables influencing the efficiency	Data envelopment analysis (DEA)	• Population density • Average pumping head • Percentage of water taken from reservoirs • Percentage of water distribution losses • Percentage of metered household and non-household properties
Maziotis et al., 2020	Chile	Evaluate the impact of external costs of unplanned supply interruptions on the efficiency of water companies	Data envelopment analysis (DEA)	• Customer density • Percentage of non-revenue water • Type of water resources • Ownership
De Santi et al., 2021	Brazil	Identify practices directed to water loss control being conducted	Survey and case study	• Pressure • Management actions • Infrastructural management • Pipe corrosion control • Leak control • Measurement errors control actions • Control of fraud and clandestine connections • Strategic planning • Investment and innovation

4.3.1 NRW function

Water loss is associated with different characteristics of the water supply infrastructures (or "physical characteristics"), water utilities management features and socio-demographic characteristics of the supplied population (Van den Berg, 2015). Nevertheless, to reduce losses, utilities must have a clear comprehension of the drivers within each of these groups. Using the linear NRW index (liters/day/km) as the dependent variable, we specify the water loss function as:

$$NRW = f(P, M, O) + \mu \quad (4.1)$$

This formula describes the relation between non-revenue water and a vector of physical characteristics of water infrastructure (P), a vector of the utilities' management characteristics (M), a vector of other factors related to where the utility is located (O), and an error term (μ).

The physical characteristics considered are those related to the service area and the distribution of the population. These characteristics are not controllable by the utility (González-Gómez et al., 2012). We included in the model the following physical characteristics variables:

a) "Households": refers to the average number of households per connection. This variable was chosen as an indicator of water network density. The hypothesis here is that the higher the population density in the network, the higher the water losses, since a denser network tends to need more pressure requirements (Van den Berg, 2015).

b) "Urban population": refers to the Ln of the population that lives in urban areas of the considered municipalities. In Brazil, water service concessions usually include only urban regions. The hypothesis to be tested is if higher population may be translated into higher demand (Van den Berg, 2015) and higher complexity in managing the service (González-Gómez et al., 2012), which can result in higher leakage rates.

c) "Energy": Indicates the share of energy cost in total operation and maintenance costs. This variable is used as a proxy for the type of the distribution system (pumping or gravity), since systems that require more pressure (i.e. pumping) have higher share of energy costs (Van den Berg, 2015; Ociepa et al., 2019).

d) “Residential”: indicates the share of residential connections in total water connections. The hypothesis to be verified is if the bigger the share of residential connections, the less NRW in the system, once a greater portion of unauthorized water consumption comes from large industrial customers (Kingdom et al., 2006).

e) “Network length”: measured by kilometers of water network. This variable was considered once the length of the network reflects the existence of a wider area to be served and managed by the supplier, and, thus, could be linked to higher levels of water losses (Gonzaléz-Gómez et al. 2012).

For the managerial group of factors, we chose characteristics that may reflect the management quality of the utility, considering a hypothesis that poor utility management increases water loss levels (Van den Berg, 2015). We considered the following variables related to utility management:

a) “Ownership”: used to identify if the service is operated by a state-owned or private-owned company. This variable was considered since the literature shows that water utilities with private participation have more incentives to be efficient than those with no private intervention (P. Carvalho et al., 2015; Tourino et al., 2022) and, thus, have lower NRW indicators.

b) “Tariff”: refers to the average water tariff of the operation, in each year. The hypothesis here is that higher tariffs would result in better service and higher resources to improve services, including NRW reduction (Mugabi et al., 2007). Also, higher tariffs would be an incentive for managers to reduce unauthorized consumption and increase billing while, with low prices, managers might find it unprofitable to invest in maintenance and leakage prevention (González-Gómez et al., 2012).

c) “Investments”: refers to the Ln of the investments made by the utility in the year of reference. Not all the investment a company makes in a year is related to NRW reduction; nevertheless, the hypothesis to be tested is if the higher the level of investments, the greater chance a bigger part goes to NRW reduction actions. The idea supporting our hypothesis is that high levels of water losses may derive from lack of resources investing in the monitoring, maintenance, and conservation of the networks (González-Gómez et al., 2012).

d) "Urban water index": refers to the percentage of urban population supplied with water. Here, the hypothesis is that municipalities with higher water index need to invest less in system expansion and, thus, may invest more in maintenance and conservation of the water service infrastructures, decreasing NRW. This variable is important to be included in the model because it relates to the perspective of problems of inequality in access to services (Cetrulo et al., 2020), which is common in developing countries, and often left aside in studies from developed countries.

Finally, as a municipal characteristic factor, we considered Ln of per capita GDP. The hypothesis to be tested is if, since higher per capita GDP is positively associated with higher water consumption (Adams & Lutz Ley, 2012; Liemberger & Wyatt, 2019), it implies in increased water losses, due to high pressure in the distribution system.

Table 4.2 summarizes the variables included in our model.

Table 4.2 – Variables' characteristics

Class	*Indicator*	*Type*	*Explanation*	*Unity*	*Source*	*Theoretical basis*
Dependent variable	linear NRW index	Quantitative	*Produced (*	l/(day.km)	SNIS	Carvalho & Sampaio, 2015
Physical factors	Households	Quantitative	Average number of households per connection	units	SNIS	González-Gómez et al., 2012; Van den Berg, 2015
	Urban Population	Quantitative	Ln of the population that lives in urban areas of the municipality	inhabitants	IBGE	Adams & Lutz Ley, 2012
	Energy	Quantitative	Share of energy cost in total operation and mainte	%	SNIS	Alsharif et al., 2008; Van den Berg, 2015

			nance costs			
	Residential	Quantitative	Share of residential connections in total water connections	%	SNIS	Kingdom et al., 2006
	Network length	Quantitative	Length of water network	km	SNIS	González-Gómez et al., 2012; Van den Berg, 2015
Managerial factors	Ownership	Qualitative	Ownership of the utility (private or state-owned)	0 = state-owned 1 = private	SNIS	González-Gómez et al., 2012
	Tariff	Quantitative	Average water tariff	R$	SNIS	Mugabi et al., 2007; González-Gómez

						et al., 2012.
	Investments	Quantitative	Ln of the investments made by the utility	R$	SNIS	González-Gómez et al., 2012
	Urban water service index	Quantitative	Percentage of urban population supplied with water	%	SNIS	Cetrulo et al., 2020
Socio-demographic factor	Annual per capita GDP	Quantitative	Ln of the annual municipal GDP	R$	IBGE	Adams & Lutz Ley, 2012; Van den Berg, 2015; Liemberger & Wyatt, 2019

In the present study, we used a multilevel model framework, due to the hierarchical characteristics of the data. The main advantage of multilevel models over traditional regression models is the consideration of the natural nesting of data, allowing the analysis of individual heterogeneities among groups in which these individuals belong to and enabling the specification of random effects in each level of analysis (Santos et al., 2016; Hair & Fávero, 2019). We proposed a hierarchical linear model with two levels (HLM2), in which, for the first level, we consider the year, and for the second level, the municipality.

4.3.2 Information on water losses in Brazil

For this study, we used data from SNIS, Brazil's official database for municipalities water and sanitation systems' operational and financial information. Data from SNIS may present some inconsistency, once, although it is the governmental official source, information is self-declared by municipality administrations and is not revised by the federal government or audited by a third party. That is why we considered it important to revise and analyze the collected data, before running the model.

Our database was composed of information of 331 Brazilian municipalities where the population is mostly urban (at least 60%), from 2017 to 2021. We adjusted the database, as explained on Table 4.3, to guarantee the data-set reliability.

Table 4.3 – Steps of the evaluation of the collected data from SNIS

Problem	Solution	Justification
Reliability of information reported by small municipalities	Municipalities with less than 10,000 inhabitants were excluded from the database.	Small municipalities usually have poor/inaccurate measuring systems, as well as little know-how and small staff to guarantee refined information regarding sanitation.
Small period of operation	To be conservative, we considered a minimum of four years of operation by the same utility owner in each studied municipality.	In our understanding, infrastructure improvements take time and adjustments do not occur as soon as a new utility provider is settled, thus, recently established operations were not included.
Missing information	We removed all municipalities with missing data and kept information from only those municipalities with four or more consecutive years of complete data.	Some information, of different variables, are missing in the SNIS database.
Inconsistent data	We removed data from municipalities where indicators of urban water service varied considerably from year to year.	Such variation is not plausible, since implementation of sanitation infrastructure takes time and, thus, the increase in the percentage of people served by water, may not vary considerably in a small amount of time. Significant decreases in water service index are also not plausible; they usually happen when catastrophes occur, and these did not happen in Brazil, during the period considered.

Table 4.4 shows the descriptive statistics of the variables used in this study.

Table 4.4 – Variables characteristics and key descriptive statistics

Variable	Min	Median	Mean	Max.
NRW	0.09	17.29	22.20	120.08
Households	1.00	1.07	1.15	3.32
Urban population (ln)	8.74	10.64	10.99	17.23
Energy	0.00	19.35	21.23	75.53
Residential	57.24	92.08	91.97	100.00
Network length	3.25	12.73	15.12	196.69
Ownership	Qualitative variable (values 0 or 1)			
Tariff	0.00	2.96	3.11	27.30
Investment (ln)	0.00	13.71	11.79	22.35
Urban Water Service	8.74	10.64	10.99	17.23
GDP (ln)	8.20	10.26	10.28	19.43

4.4 RESULTS AND DISCUSSION

4.4.1 NRW drivers in Brazil

Table 4.5 presents the results of the HLM2 estimation, using a stepwise procedure. The results reveal that a small portion of the explanatory variables introduced in the model have a significant effect (at 5%) on water loss, measured by the linear NRW index. Such fact goes against some findings in the literature that indicate a higher number of factors to be significant in determining water loss rates (Adams & Lutz Ley, 2012; González-Gómez et al., 2012; Van den Berg; 2015). Nevertheless, our model presents a level 2 intraclass correlation (ICC) of 0.96907, meaning nearly 97% of the NRW indexes variance in our database is explained by the variables included in the final model.

Regarding physical factors, three variables showed to be statistically significant: urban population size, residential share of total customers and network length. On the other hand, from all the utilities' management characteristics, only ownership showed to be significant. At last, our socio-demographic variable, the municipal GDP, is not significant in explaining NRW levels in our model.

Table 4.5 – Estimation results of the random intercepts model

	Value	**Std. Error**	**DF**	**t-value**	**p-value**
Intercept	-3.912232	8.076179	1280	-0.484416	0.6282
Year	-0.288334	0.136301	1280	-2.115414	0.0346
Urb. Population	3.713078	0.573373	1280	6.475852	0.0000
Residential	-0.131565	0.052184	1280	-2.521159	0.0118
Network length	-0.090693	0.024901	1280	-3.642096	0.0003
Ownership	-0.773982	0.254161	1280	-3.045246	0.0024
Variance decomposition	**Value**	**Std. Error**	**Z**		**p-value**
Var(v0j)	330.755386	26.8313803	12.327185		0
Var(v1j)	3.890934	0.3966099	9.810481		0
Var(e)	10.680313	0.4890517	21.838820		0
Intraclass correlation (ICC) of level 2: Municipality			0.96907		
Likelihood ratio test			-5236.901		
Number of Observations			1.616		
Number of Groups			331		

The size of the population is a factor that water utilities cannot control. In our model, we used information of the urban population to measure population size, and such variable was shown to be statistically significant (at 1%). We found a positive relation between urban population and NRW, which may be explained by the fact that larger populations result in higher demands for water in the supplying system (González-Gómez et al., 2012), increasing pressure and, thus, water loss (Van den Berg, 2015). Higher populations may also indicate a higher complexity in managing the water services (González-Gómez et al., 2012) and, thus, more difficulty in controlling water loss. Nevertheless, the literature also presents the inverse explanation; for instance, Adams and Lutz Ley (2012) argue that growing populations put more pressure on the water availability, increasing the marginal cost of water and, thus, increasing the pressure for water loss reduction, which means that the relation between population size and NRW should be negative. That may be true in specific locations, where water availability is a more relevant concern, or where there is a more propagated cultural concern or educational programs regarding rational water use and sustainability; it was not the case, though, of the Brazilian municipalities included in our database.

The negative and significant correlation (at 5%) between the share of residential connections and NRW shows that, in line with Kingdom et al. (2006), a great non-revenue water in Brazil, from 2017 to 2021, came from non-residential connections. For these authors, a valid explanation for such a fact is that industrial customers usually have enough resources to bribe utility staff and management, consuming water without paying.

One may claim that, in Brazil, a great part of the population does not have available financial resources to pay for the used water, and, thus, end up engaging in frauds. Indeed, illegal residential connection to the network is still a common practice in vulnerable areas in Brazil (mainly slums and settlement areas; Marques & Saraiva, 2017; Sampaio & Sampaio, 2020; De Santi et al., 2021). Nevertheless, it is important to cite that in Brazil, there is a kind of tariff that is used to overcome this problem: the "social tariff" is a more accessible price of drinking water for people with low incomes, used both in private and public water utilities (Barbosa & Brusca, 2015). The social tariff may be a plausible explanation of the negative relation between NRW and share of residential connections. Indeed, despite helping to guarantee the universality and affordability of water services (Martins, Antunes, & Fortunato, 2020), the implementation of this kind of tariff helps in the decrease of non-authorized consumption.

Regarding network length, our results do not support the hypothesis that the existence of a wider area to be served by the supplier should be linked to higher levels of water losses. Nevertheless, most studies that support this finding refer to analysis in developed countries (González-Gómez et al., 2012, Van den Berg, 2015; Ociepa et al., 2019). In developing countries, such as Brazil, cities are expanding at a rather fast pace and universalizing water supply is still an ongoing priority (Cetrulo et al., 2020; Sampaio & Sampaio, 2020), meaning a great part of the water service infrastructure is still relatively new. Also, more than length, the complexity of the area (for instance, orography and urbanization model) can have a stronger correlation to water loss, since it affects the structure of the networks, costs of pumping water (González-Gómez et al., 2011), as well as costs of interventions to eradicate leakages and visits to socially vulnerable areas seeking to eliminate illegal connections.

One may highlight that, regarding the share of energy expenses on total expenses, the result from our estimation was quite surprising, since many works depict the positive relation of such variable with NRW indexes (Van den Berg, 2015; Vilanova, Magalhães Filho, & Balestieri, 2015; Alsharif et al., 2008; Ociepa et al., 2019). A plausible justification may be that the chosen variable, which expresses the share of total costs addressed for energy, may not be suitable. Brazil has faced, in recent years, prolonged droughts that significantly impacted the reservoirs used for generating hydropower energy, the country's main source of energy nowadays (Hunt, Stilpen, & Freitas, 2018; Cuartas et al., 2022). Consequently, there has been a great variation of energy price, meaning increases in the share of energy cost may be due to its high price and not necessarily to consumption increase.

Ownership was the only managerial characteristic to present a statistical significancy (at 1%) in the final model, demonstrating the negative relation between privatization and water losses. This finding is in line with studies regarding efficiency, which identify water loss rate as one of the most relevant inefficiencies for water utilities (Marin, 2009; Vilanova et al., 2015; Maziotis, Villegas, Molinos-Senante, & Sala-Garrido, 2020) and point out private operators as more efficient (P. Carvalho et al., 2015; Tourino et al., 2022). A great part of private operators succeeded in reducing water losses (Marin, 2009; P. Carvalho et al., 2015) and the explanation for such fact may be simple: reductions in water losses represent a revenue for the service provider (Amaral et al., 2023), an important incentive for investments with this focus for water supply utilities.

Nevertheless, our results go against findings from research in developed countries, such as Spain, that indicate that, given the low cost of raw water in relation to the estimated opportunity cost of saving this natural resource, private operators might have little incentive to control water loss and, therefore, wasting water becomes a profitable strategy for private utility managers (Picazo-Tadeo, González-Gómez, & Sáez-Fernández, 2009; Sáez-Fernández et al., 2011; González-Gómez et al., 2012). That is another good evidence that benchmarking developed countries' actions on NRW losses may not be a good strategy for Brazil.

The negative relation between NRW and privatization may be also explained due to political aspects state-owned utilities face. First, municipal governments facing budgetary difficulties probably devote fewer resources to the reduction of water losses, focusing on spending towards more visible and 'voter-friendly' policies (Marin, 2009; González-Gómez et al., 2012; Grover & Lucinda, 2021). Secondly, attempting to reduce apparent losses due to unauthorized consumption may have a high political cost, considering that a great percentage of illegal residential connections occur in the poorest areas and that tackling unauthorized consumption could lead to strong social reactions (Marin, 2009; González-Gómez et al., 2012). Thirdly, weak levels of environmental sensitivity and a limited awareness of the value of water result in little pressure on the political class in this regard (Marin, 2009; González-Gómez et al., 2012).

Although authors claim that higher tariffs would result in more available resources to be invested in commercial actions and leak detection and elimination (Mubagi et al., 2006; Marin, 2009), tariffs did not show to be a significant variable in our model. From our results, we may infer that, even if a company charges higher tariffs, not a significant share of the resources derived from elevated revenues are implemented to NWR elimination actions. It also indicates the existence of a hidden cross-subsidy that benefits unauthorized consumers and those who benefit from metering inaccuracies and that costs claimed for poor technical management are being passed on to the user (González-Gómez et al., 2011).

Nevertheless, it is important to know that inefficient management and bad service permit lower billing levels, and, in the meantime, low billing levels make it difficult to improve the service (González-Gómez et al. 2012). Also, not the value of the tariff, but resources' management should define a company's ability to focus on NRW reduction, since the literature demonstrates that utilities that at least cover their operation and maintenance expenses through revenues face lower levels of NRW (Van den Berg, 2015). Finally, higher water losses correspond to higher production costs and such costs usually are passed to consumers (Arsesp, 2020), indicating an incoherence, since consumers are penalized by the utility's inefficiency.

Investment makes it possible to decrease leakages and reduce the amount of apparent losses, for example, by allowing improvements in the metering system, leakage detection and network renovation (Marin, 2009). Nevertheless, investments showed not to be significant. In the same line of the results for the variable “tariff”, that indicates that municipalities in Brazil that have higher levels of investments may be directing such resources to other uses, such as water production amplification, since in the past years, the country has been facing water insecurity issues (Sousa & Fouto, 2019; Sousa et al., 2022; Getirana et al., 2021), as well as addressing infrastructures deficits (Sampaio & Sampaio, 2020; Pinto et al., 2021). Another reason for this may be that most service utilities in Brazil are state-owned companies, and most utilities with public management still count on public resources to improve their services (Barbosa & Brusca, 2015), thus, the variable used in our model does not capture other investments besides the operators' itself. Finally, as already brought up, one may say that municipal governments facing budgetary difficulties probably devote fewer resources to the reduction of water losses since, in those cases, public managers may prefer to allocate the available funds to other activities that render them greater political prestige (González-Gómez et al., 2012).

The fact that GDP did not represent a significant variable to explain NRW variability in Brazil may be due to socio-demographic particularities of the country. If, in one hand, higher per capita GDP is associated with higher water consumption (Adams & Lutz Ley, 2012; Liemberger & Wyatt, 2019; Sousa & Fouto, 2023) and, thus, higher pumping and pressure, on the other hand, locations with lower per capita GDP in the country are usually poorer regions, where the level of investments on leakage detection, fraud control, and infrastructure renovation is lower.

One must highlight that De Santi et al. (2021), who developed a survey with Brazilian utility managers, present other variables, such as pressure or the level of innovation. These were not included in our model due to the lack of such information, so upcoming research should consider them.

4.4.2 Overcoming NRW high indexes in developing countries

It is important, for water utilities' managers and governments in developing nations to have in mind that elevated NRW detracts water utilities from reaching their goals of full-service coverage, at a reliable level of service at an affordable price (Liemberger & Wyatt, 2019). Anyway, Brazil has some important examples of efficient actions that may be used as benchmarks for places, within the country or in other nations, where social and demographic characteristics are similar. Benchmarking managerial practices are useful in sectors and areas where there is low potential of competition as well as institutional regulations that restrict managerial decisions, contributing to the existence of inefficient practices (Sáez-Fernández et al., 2011).

One good example comes from the biggest water supply utility in Brazil, the state-owned company called Companhia de Saneamento Básico de São Paulo (Sabesp), which has successfully used "performance-based contracts" to fight against real losses on the company's concession area. Performance contracts are built on the idea of compensating the contracted company for achieving the target results, not only for executing a series of tasks (IFC, 2013). With this kind of contract, there are sufficient incentives and flexibility to ensure accountability for performance, since the payment is linked to actual results achieved in NRW reduction (Kingdom et al., 2006; Marin, 2009).

Another example of efficiency in reducing non-revenue water comes from the biggest private company operating in the country, Aegea. This company has developed a program ("Come with us", in free translation), which consists in traveling street by street, regularizing connections, mapping and connecting houses to the network and ensuring access to sanitation to low-income families. It aims at regularizing and expanding access to treated water for families living in favelas and other vulnerable sites (Aegea, 2022). The company also implements an action called "Social license to operate", which is a communication program aiming at getting permission to act in a territory, assigned by the local population.

4.5 CONCLUSION

Brazil has a serious problem when it comes to water loss, since it has high levels of NRW, and has been facing water shortages over the past years. Thus, a new regulatory framework, that addresses this issue directly is more than welcome, it is needed. Since the current regulation is still vague and no specific goals have been addressed, water utilities still have few regulatory incentives to undertake the necessary actions to reduce NRW.

Despite the lack of national goals and deadlines of water loss reductions, Brazilian utilities must efficiently direct their efforts to overcome the problem. Nevertheless, using benchmarks and findings in the current literature, which usually refer to the reality of developed countries, may not be the way. In this study, we demonstrated that water loss drivers in Brazil differ from the drivers more frequently found in the literature, reinforcing the need for research that focuses on the country's particularities. This is because only four of the ten factors considered, chosen from information on available literature, were statistically significant to explain NRW levels in Brazil: population size, share of residential consumers, network length and utility ownership. The kind of relation with water loss levels (positive or negative) also differed in some cases from findings in available studies, reinforcing the need to consider regional particularities when studying ways to reduce NRW and implementing public policies.

Considering this results, ind in the current literature, this work presents variables that managers must prioritize when planning the strategy to reduce NRW, seeking to preserve water resources as well as to achieve better financial returns on the operations.

Nevertheless, there may be other variables that influence the rates of NRW in Brazil and other similar nations, like socio-demographic variables, which were not considered in our model due to the lack of such detailed and reliable information for the analysis period. Also, most of the variables considered in our model, related to physical and managerial aspects of operation, were considered based on studies from developed countries, meaning that there might be relevant variables, specific to developing countries, that were left out. Considering that, future work, focused on other developing countries and that include new variables to the model, may fill this gap.

Also, this article presents some actions adopted by companies acting in the country which, so far, shown to be efficient in reducing NRW. Such actions may be used as bechmarks

5. DISCLOSING WATER CONSERVATION BY WATER UTILITIES[5]

Abstract: Using score technique, we created a Water Security Index (TWSI), to evaluate disclosed information from 15 Brazilian water utilities' preparedness to extreme water events, considering water and sanitation companies' annual reports. The so called TWSI is calculated considering seven dimensions: (*i*) Climate changes and their impacts on water availability; (*ii*) Water availability evaluation and measurement; (*iii*) Improvements in supply infrastructure systems; (*iv*) Demand-side infrastructure improvements; (*v*) User's awareness creation; (*vi*) Water availability prediction; and (*vii*) Actions to prevent water availability issues. The results point to a rather paradoxical situation, since, on one hand, TWSI was far from the maximum score, and on the other, the impacts of global change, that will increase the frequency and magnitude of extreme weather events, are becoming a bigger concern in Brazil. Not giving the necessary attention to this issue means disregarding the fact that water, the core business of water utilities, will become increasingly scarce. User's awareness creation was the dimension with a better score, while water availability evaluation and prediction as well as demand-side infrastructure improvements are the aspects of water security receiving least attention by water utilities managers. This study evidences that water companies may have a clear understanding of climate changes' impacts on the water industry but fail to communicate their adopted and planned actions.

Keywords: Climate changes, water availability, water security, awareness.

5.1 INTRODUCTION

The World Economic Forum issues an annual publication regarding the top risks society will face, and year after year climate change associated risks appear in some of the top positions, both in the short and in the long term. Recent droughts in several parts of the world may be one of the first concrete symptoms of human-induced climate change (Santos et al., 2019). Nevertheless, some nations still fail to identify and address such

---

[5] Co-author: Nuno M.M.D. Fouto. This version of the article is going to be submitted to the special edition named "Corporate Governance, Integrated Reporting Framework and Sustainable Business Practices in Emerging Market" of the Journal of Accounting in Emerging Economies (Impact factor 3.65), which opens in December/2023.

risks, while increasingly uncertain weather events, along with over exploitation, contamination of resources and lack of infrastructure, cause water resource scarcity and impact water utilities' activities (Pinto et al., 2021). It is a management matter to overcome these challenges, create resilience to water scarcity and guarantee adequate water supply.

A great part of the existing studies in the literature on the water industry focus on managerial performance, ignoring other social dimensions of the management of water resources, such as sustainability (Sáez-Fernández et al., 2011). This dimension becomes crucial in a scenario of increasing uncertainties regarding water availability and water supply systems, meaning that water providers should encourage a more conscious consumption as well as take actions to increase water security. In the water supply sector, the robustness and resilience of systems depend on 'preparedness measures' able to establish a link between resources availability, utility costs, tariffs, and demand (Pinto et al., 2021). In this sense, this study intends to provide evidence for the evaluation of extent to which the Brazilian water industry will bear extreme weather conditions in the future. More specifically, the objective is to understand the degree of disclosed preparedness to face extreme events that may compromise water availability, and which are the most frequent and less frequent actions taken by water utilities aiming at such a goal. The hypothesis is that, in recent years, water issues has become a more material factor to water supply utilities, increasing the discussion of this matter in the companies' annual reports.

5.2 LITERATURE REVIEW

5.2.1 Water as a public good

Drinking water is a natural resource and, as such, must be consumed sustainably (Gilbertson et al., 2011). Nevertheless, as a public good, which has as intrinsic characteristics non-rivalry and non-excludability (Kolstad, 2011), there is no market signal for water, as private goods have. That means that its water price may be below the optimal price, as several scholars have stressed (Renzetti, 1992; Timmins, 2002; Arbues & Barberan, 2004; Olmstead, 2010; Oliveira & Ferreira, 2021).

In the 21st century, many scholars have pointed out the need to address the quality and availability of water sources, as several nations suffer from problems of water scarcity and degradation of the quality of water resources (Wang et al., 2019). A well- designed public policy needs to reflect not only the objectives of society, but also any trade-offs associated with constraining the hydrologic and economic dimensions of a system across scope, scale, time, and space dimensions (Loch, Adamson, & Mallawaarachchi, 2014). This is because, nowadays, various cities around the world strive to manage water resources in the face of population increases, demand for water-intensive activities and high costs (including environmental costs) of developing new reservoirs (Olmstead & Stavins, 2009).

5.2.2 Climate change associated risk to water supply industry

Climate change is an external driver, potentially affecting both demand and availability of natural resources (Arnell & Delaney, 2006). In Brazil, in the recent years, there have been cases of intense droughts in important regions and cities, impacting water supply (Santos et al., 2019; Sousa and Fouto, 2019; Sousa et al., 2022). In this context, water utilities rise as strategic service providers facing many challenges, such as the need to ensure universal access to water and sanitation services in a context of limited availability of water and uncertainties regarding the effects of climate change (Barbosa and Brusca, 2015).

The increase in the number and duration of water shortage periods is a trend to be considered for any water system planning in Brazil over the upcoming decades (Sousa et al., 2022). Arnell and Delaney (2006) indicate several potential physical impacts of climate change on the water supply system, such as (*i*) alterations on the reliability of raw water sources by changing the frequency of flows and recharge; (*ii*) possible alterations in the reliability of the supply infrastructure; and (*iii*) physical damages in facilities and water quality due to increasing the frequency of floods. This study focuses on the first two impacts, which may be related to water scarcity.

5.2.3 Water utilities reporting

Reporting is a way of communicating to stakeholders the degree of commitment to different causes. Since water utilities play a critical role in sustainable development, by ensuring the protection of the quality of water resources and the continuous supply of water to current and future generations (Cantele, Tsalis, & Nikolaou, 2018), they should communicate to stakeholders their actions and strategies, including the ones aiming to create resilience of water supply systems.

There is a limited number of studies which focus on water utilities accountability and legitimacy strategy for sustainability issues (Cantele et al., 2018). Cases in European countries have been the most analyzed in the available studies. For instance, Larrinaga-González and Pérez-Chamorro (2008) evaluated how Spanish public water companies disclose sustainability information. Marques, Da Cruz and Pires (2015) proposed an urban water services sustainability scorecard based on a multicriteria decision analysis model, considering the Portuguese context. Similarly, and considering a sample of Portuguese water companies as well, Molinos-Senante et al. (2016) created a synthetic indicator embracing economic, environmental, and social performance indicators. Outside Europe, Tregidga and Milne (2006) identified a shift in water utilities in New Zealand, from companies that sustainably manage resources to ones that actually practice sustainable development.

Nowadays, the most used references for sustainable reporting are the Global Reporting Initiative (GRI) and the Sustainability Accounting Standard Board (SASB). There is also the Carbon Disclosure Project (CDP), which includes the precise identification of risks over water (Truant, Corazza, & Scagnelli, 2017), but focusing on industry consumption. Finally, there are the 17 main sustainable development goals (SDG), which contains sustainable targets to be achieved by companies and nations by 2030. All these references may be used for companies in the water supply industry as guidelines on the reporting; nevertheless, these guidelines may be sometimes insufficient, indicating that a new industry-specific sustainability reporting standard is important (Cantele et al., 2018). This is even more crucial since water utilities fail to inform about some material aspects of water management, such as water recycling, network resilience, water sources, and effluent quality (Truant et al., 2017; Cantele et al., 2018).

5.3 METHODOLOGY

This research is built on an integrated methodological framework, associating content analysis with scoring technique. This is a compound technique that is usual in the analysis of the sustainability reports (Arnell & Delaney, 2006; Demertzidis, Tsalis, Loupa, & Nikolaou, 2015; Cantele et al., 2018).

Content analysis is a standard methodology in the social sciences for studying the content of communication (Sobhani, Amran, Zainuddin, 2012) and is widely adopted in social and environmental disclosure studies (Milne and Adler, 1999; Michelon et al., 2015; Papoutsi and Sodhi, 2020). We conducted the content analysis, implementing a coding procedure, followed by the interpretation of the coded content (Gaur & Kumar, 2018), to evaluate water availability disclosure in annual reports of Brazilian water utilities. To enhance the reliability, in the present work two researchers (the coauthors) first performed a pilot test of the coding activity.

For this step, we used a predefined set of indicators. Following the highlights of Molinos-Senante et al. (2016), the indicators selection was based on the following criteria: representativeness, relevance, reliability, sensitivity, ease of understanding, comparability, and transparency. Considering that, we ended up with a list of 28 items to be verified in each annual/sustainability report, regarding water security and related aspects, which may be divided in seven dimensions: (*i*) Climate changes and their impacts on water availability; (*ii*) Water availability evaluation and measurement; (*iii*) Improvements in supply infrastructure systems; (*iv*) Demand-side infrastructure improvements; (*v*) User's awareness creation; (*vi*) Water availability prediction; (*vii*) Actions to prevent water availability issues.

After the content analysis, we conducted a scoring technique, aiming at quantifying the information of the sustainability reports under a systematic manner, following Cantele et al. (2018). The idea behind this technique is to evaluate environmental reports, by means of a numerical scale, to identify the completeness of information disclosures according to a predetermined set of indicators. As Demertzidis et al. (2015) point out, there is a range of scholars that have established scoring methodologies to quantify, in a comparative way, the nonsystematic provision of environmental information through a business environmental report.

In the present study, using the same score technique as Sobhani et al. (2012), we calculated disclosure indices by considering the number of items disclosed divided by the number of items on a predefined set of indicators. With the used coding procedure to capture the disclosure of water security information, the company scored 0 if it failed to provide information on a specific predefined indicator, or 1 if the report brought up information on it. Considering the total number of the selected indicators, the Total Water Security Index (TWSI) can be calculated as the sum of the scores achieved within all indicators (Equation 5.1).

$$TWSI = \sum_{i=1}^{3} CC + \sum_{j=1}^{4} WAE + \sum_{k=1}^{10} SSI + \sum_{l=1}^{4} DSI + \sum_{m=1}^{2} UAC + \sum_{n=1}^{2} WAP + \sum_{o=1}^{3} PA \tag{5.1}$$

CC: Climate changes and their impacts on water availability.
WAE: Water availability evaluation.
SSI: Improvements in supply-side infrastructure.
DSI: Improvements in demand-side infrastructure.
UAC: User's awareness creation.
WAP: Water availability prediction.
PA: Preventive actions.

In our model, $0 \leq \text{TWSI} \leq 28$. This means that TWSI score ranges from zero, when an examined report does not provide any information concerning water security, to 28 when a sustainability/annual report covers all aspects of sustainable water management performance.

For each firm, we analyzed sustainability reports, and when such a report was not available, we evaluated the annual report. We ended up with a sample of fifteen water supply companies operating in Brazil, for which we have from three to four years of observation, summing up 55 analyzed reports. These companies account for over 3,000 operations, supplying 65,9% of the Brazilian population.

5.4 FINDINGS AND DISCUSSION

From the fifteen companies in our analysis, most of them (10) state-owned companies (Table 5.1). It is important to have this overview regarding ownership, since pressures and motivations towards sustainability reporting are differentiated between the private and the public sector (Cantele et al., 2018). In the case of Brazil, this information is even more important since the regulatory framework, established in 2020, focuses on increasing competition, creating a more secure environment to attract private companies.

Table 5.1 – Number of reports segmented by type of ownership

	2019	**2020**	**2021**	**2022**
State-owned	10	10	10	6
Private-owned	5	5	5	4
Total	15	15	15	10

The scores verified for each factor and for the TWSI are shown in Table 5.2.

Table 5.2 – Evolution of scores in the different factors that compose the TWSI

Class of indicators		Actions to prevent water availability issues (max = 3)	Climate changes and their impacts on water availability awareness (max = 3)	Demand-side infrastructure improvements (max = 4)	Supply-side infrastructure improvements (max = 10)	User's awareness creation (max = 2)	Water availability conditions (max = 4)	Water availability prediction (max = 2)	**TWSI (max = 28)**
Average score/ year	**2019**	2.13	1.20	0.53	6.67	1.80	1.83	0.27	**14.40**
	2020	2.00	1.67	0.60	6.93	1.80	2.33	0.53	**15.73**
	2021	2.47	1.93	0.13	6.60	1.87	2.21	1.00	**16.20**
	2022	2.60	2.00	0.70	7.40	1.90	2.50	0.80	**17.90**
Statistics	**Mean**	**2.30**	**1.70**	**0.49**	**6.90**	**1.84**	**2.14**	**0.65**	**16.06**
	S.d.	**0.28**	**0.36**	**0.25**	**0.36**	**0.05**	**0.32**	**0.32**	**1.45**
	Δ from max score	**- 23,2%**	**- 43.3%**	**- 87.7%**	**- 31.0%**	**- 7.9%**	**- 46.5%**	**- 67.5%**	**- 42.6%**

5.4.1 Total Water Security Index (TWSI)

On average, sustainability reports from water utilities score around 16.06 out of 28.00 (57.4% of the maximum TWSI score), meaning there is a considerable number of indicators regarding water security that water utilities do not include in their reporting. That does not mean that the analyzed companies oversee such indicators, but that they do not communicate it to their stakeholders through their sustainability/annual reports.

Throughout the analyzed period (2019 – 2022), the gap between maximum TWSI score and the average achieved from the analyzed water utilities has shrunken, meaning that there has been a positive evolution on disclosure regarding the aspects of water security. This may be explained by the increase in the occurrence of droughts in important Brazilian cities, in the past two decades (Cunha et al., 2019; Sousa & Fouto, 2019; Sabesp, 2020; Saneago, 2021; Sanepar, 2023), a factor that is proven to shape actions towards water conservation (Sousa et al., 2022).

On average, state-owned companies showed a higher TWSI than private ones (Table 5.3), meaning that public companies report more their actions related to water security than private owned water utilities. The results may be linked to the fact that public utilities usually are more flexible and proactive than their private counterparts in dealing with shortages and water (Kallis et al., 2010). However, such flexibility may be restricted sometimes, since there are political pressures and other social obstacles that restrict public water providers actions (Loch et al., 2014; Santos et al., 2019; Embasa, 2020; Grover & Lucinda, 2021; Pinto et al., 2021).

One may verify, as Table indicates as well, that private-owned companies are presenting an increase trend on their TWSI, which was not verified for state-owned companies.

Table 5.3 – Average TWSI

	2019	**2020**	**2021**	**2022**	**2019-2022**
State-owned	15,3	17,1	16,2	17,5	**16,5**
Private-owned	12,6	13,0	16,2	18,5	**15,1**

5.4.2 User's awareness creation (UAC)

The class of indicators with the closest score to the maximum was "user's awareness creation", which includes two indicators: (*i*) efficient water consumption through educational programs; and (*ii*) efficient water consumption through economic incentives. For the first, all companies disclosed their actions on educating the population to use water consciously and such information was brought up almost every year - only two companies fail to bring this topic on all their analyzed reports. This is a positive result, since educational campaigns create awareness, indicating how the adoption of certain behaviors can make a difference and induce individuals to act more responsibly (Lowe et al., 2014; Ramsey et al., 2017; Gómez-Llanos et al., 2020).

Regarding economic instruments, only three companies did not mention on their annual/sustainability reports any kind of incentives (like tariffs), in none of the considered years. A proper management of water bodies used for human supply demands, among other actions, the use of economic instruments to indicate scarcity situations and to encourage the rational use of water (Oliveira & Ferreira, 2021). It is important to highlight that, without a clear signaling of its value, water becomes a vulnerable commodity and is increasingly scarce. The continuous increase in demand and the lack of more rational use are menaces to this resource.

Charging for the use of water resources is a way to discipline the population for the use of water. Some recent studies show that, in Brazil, economic incentives have shown to be efficient instruments in promoting water consumption reduction (Sousa and Fouto, 2019; Sousa et al., 2022). Despite that, in our sample, only two companies explicitly related using tariffs to creating awareness towards rational use (Sabesp, 2020; CASAN, 2021).

Another important fact regarding economic incentives that one must emphasize is that tariffs may come with problems of equity and fairness considering the social effectiveness of economic measures (March et al., 2015). That may be one of the reasons most of the companies, when addressing tariffs on their reports, mentioned the implementation of "social tariffs", which correspond to a lower tariff of drinking water, for households with low incomes (Barbosa & Brusca, 2015). Even though social tariffs and climate changes might not immediately seem connected, in the future, the political connection between them will become unavoidable, since the cost of climate change adaptation is pushed onto consumers without regard to their ability to pay, meaning that those who can make the case for accelerated investment without alienating low-income customers will be more successful (Gasson, 2023).

5.4.3 Preventive actions (PA)

The second class of indicators closer to the maximum possible score includes actions implemented to prevent water availability issues. In the study, we considered three actions that are indirectly related to water management: (*i*) CO_2 emissions reduction, (*ii*) riparian vegetation conservation/recovery and (*iii*) improvements in sewage treatment systems. These actions help to reduce greenhouse gases in the atmosphere, contributing to the fight against climate change, as well as maintaining adequate water quality and quantity.

For the first action, most reports address the issue of emission reduction, although some of the companies have not yet established reduction goals nor even have their greenhouse gas emissions inventory (a few of them implemented their first greenhouse gases emission inventory only in one of the years of the analyzed period). The importance of addressing such issues remains on the fact that changes in rainfall precipitation and recent droughts throughout the world are shown to be linked to anthropogenic climate change (Kooperman, et al., 2018; Santos et al., 2019, Getirana et al., 2021).

For the second action, i.e. riparian vegetation conservation/recovery, almost all companies disclosed actions on their reports on this issue, showing that, with exception of one company, they can relate maintaining and recovering riparian vegetation to water quality and availability. The importance of maintaining, conserving, and recovering these areas relies on the fact that riparian zones are the interface between aquatic and terrestrial systems along inland water bodies, and they have a critical role in diverse ecological processes, such as water purification and microclimate regulation (Bennett, Nimmo, & Radford, 2014; González et al., 2017).

For the last action, all companies mentioned improving sewage treatment on their annual reports, although two of the analyzed companies failed to mention these actions in all the considered years. Improvements on sewage treatment are crucial for water utilities' own activities, since degradation of water quality, especially in urbanized areas, is aggravated by deficiencies in sewage infrastructure and inadequate disposal of untreated wastewater (Piffer, Tambosi, & Uriarte, 2022). Additionally, it is important to consider that in Brazil, it is provided in the law that water and sewage operators should seek ways to, by 2033, attain universal sewage collection and treatment, since nowadays, very few companies have already reached universalization. Thus, mentioning improvements in sewage treatment in annual reports is a way of utilities to communicate to stakeholders that the law is being enforced.

5.4.4 Improvements in supply-side infrastructure systems (SSI)

SSI was the third class with the smallest gap between the maximum possible score and the verified score. This is the class with the highest number of indicators, and it contains different engineering improvements that increase the volume of water available in the supply system. In this research, we considered actions related to infrastructure improvements, which may be divided into three groups: (*i*) new sources (new superficial or ground water extraction, water body transposition, desalination and/or water reuse); (*ii*) infrastructure improvements (network linkages, increase on raw water treatment capacity and enhancing distribution capacity); and (*iii*) water loss reduction (including network and metering improvements).

Diversification of water resources utilization has been confirmed as an important part in adaptive strategies, including overcoming water shortage (Hochstrat, Wintgens, Kazner, Melin, & Gebel, 2010). For this group, it is important to remember that some improvements on supply systems are not possible in some of the operations of the analyzed utilities. For instance, desalination is not a feasible solution in operations that are located far from the coastal areas. Also, the current water availability makes the use of desalination solutions, which are more costly, less attractive than other solutions, such as the development of new or enhanced reservoirs, or even transpositions.

For the second, for Santos et al. (2019), adaptive management regimes should include not only preparedness measures at the ecosystem and resource level, but also at what they call “human systems level” (e.g., distribution and choice of infrastructure). That is why a great part of the literature on urban water supply has focused on assessing the sustainability of physical and engineering aspects of water supply systems, in particular the water distribution networks (Marques et al., 2015; Molinos-Senante et al., 2016). Improvements in this sense are considered structural investments, corresponding to the traditional investments with engineering works and related activities, aiming at the universalization of service (Compesa, 2021).

For the third group of factors, one must highlight that, in a context of increasing worldwide water shortage, loss reduction in drinking water networks is a key objective (Pillot et al., 2016), being directly associated with the optimization of the use of a finite natural resource and restricted access (SNIS, 2022). In our sample, all companies mentioned, in almost every year, their efforts to identify leaks, refit old networks and replace and add new water meters, actions to reduce water loss.

5.4.5 Climate change awareness (CC)

Climate change will cause shifts in the global hydrological environment (Ostad-Ali-Askar, Su, & Liu, 2018), and may increase domestic water demand peak (Downing et al., 2003), adding complexity in water supply systems. In the scenario of climate change, current paradigms of water management supply may prove to be inadequate (Santos et al., 2019) meaning it is necessary to apply actions in order to increase the reliability of the distribution system (Arnnel & Dellaney, 2006). The class of indicators related to climate change awareness comes in fourth place and includes three indicators: (*i*) mention of global warming or climate change; (*ii*) mention of extreme events; (*iii*) mention of the IPCC report.

All the analyzed companies, but one, in at least one year, dedicate some paragraphs on their annual/sustainability report to address the effects of climate changes on water availability. Nevertheless, only two companies succeeded in linking climate changes to revenue decrease, costs increase, lower credibility and even potential lawsuits (Aegea, 2020; Sabesp, 2021). Our results are in line with Arnnel and Dellaney (2006), who, analyzing water companies in the UK, in the mid-2000s, concluded that, while awareness of climate change is high in the water supply industry, concern over the impact of climate change varies among companies.

Worldwide climate change has as a significant impact on the increase in severity and frequency of extreme weather events. Such events include heavy rainfall, floods, and droughts (Khan et al., 2015; Getirana et al., 2021), among others, each of which can potentially impact water supply operations by affecting water catchments, storage reservoirs, water treatment processes or even the distribution systems infrastructures (Khan et al., 2015). There is a need for water companies to lead change and coordinate efforts by developing formal strategies for building resilience to extreme events, including the implementation of a water quality management system and the development of specific incident response plans (Khan et al., 2017; Tiedmann et al., 2023). The mention of extreme events was verified by all companies from our sample but one, and this result is in line with our expectations, since some Brazilian cities have been facing such kind of weather events in recent years (Sousa & Fouto, 2019; Embasa, 2020; Sabesp, 2020; Getirana et al., 2021; Saneago, 2021; Sousa et al., 2022; Sanepar, 2023) and many cities in the country face imminent water rationing. Nevertheless, the degree of concern about the impacts of climate change and precise adaptation to increase resilience varied among companies, which may be due to unique geographic conditions where the utilities operate.

Finally, the mention of the IPCC's reports was considered as a sign that companies take into consideration scientific evidence when arguing about the importance of evaluating climate change's probable impacts and ways of managing it. The IPCC reports have highlighted that unabated regional land-cover change and global warming are causing a cascade of persistent dry conditions around the globe (Getirana et al., 2021). Nine, out of 15 companies, mentioned in their reports the IPCC findings, but none in all the years considered in our research.

Our results related to CC are not in line with some findings in the past literature, which indicates that climate change was generally seen as having relatively little effect over the next years, compared to other drivers of change (Arnnel and Dellaney, 2006). This fact indicates that, in the present years, there has been a shift on water companies mindset related to the issue. In the early 2000's, water managers showed to be more concerned about the implications of increases in demand for water, due to demographic change and population movements, than about the implications of climate change.

One remarkable finding from our research is that, in Brazil, the SSI had a better score when compared to CC, which may be explained by the fact that the country still faces considerable gaps in water supply — over 30 million people still do not have access to clean water (SNIS, 2022) — and that, as already mentioned before, a recent legal regulatory framework establishes universal water supply goals (*Lei n. 14.026*, June 15, 2020). In this scenario, players in the industry see as a bigger incentive the investment in expanding services rather than to create resilience. Nevertheless, it is important to highlight that one of the evaluated companies stated that the expansion of sanitation does not exclude from our priorities the permanent strengthening of water security (Sabesp, 2020).

5.4.6 Water availability evaluation (WAE)

The class of "water availability evaluation" indicators is next on the rank of issues most addressed on sustainability/annual reports. It includes four indicators: (*i*) mention of water shortage experiences; (*ii*) mention/explanation of a water security plan; (*iii*) inclusion of the topic "water security" in the materiality matrix; and (*iv*) quantitative information of water resources availability.

All companies mentioned water shortage experiences in at least one of the considered years from our evaluation period. In Brazil, at least four W&S utilities from our sample have faced major droughts in their operation areas in the recent and other three operate in areas where there are systemic droughts. Although we considered the result positive, once water companies have a relevant role contributing to create resilience in water supply, Gentirana et al. (2021) highlights the need of a coordinated national drought-mitigation plan not only by the industry, but also researchers, policymakers, industry, the public sector, and civil society.

A water security plan (WSP) is a preventive, comprehensive risk assessment and management approach to ensure drinking water safety (Rinehold, Corrales, Medlin, & Gelting, 2011; String & Lantagne, 2016). WSPs are instruments elucidating current and future actions needed to increase water availability as well as water scarcity resilience. In line with the fact that all water utilities from our sample have faced water shortage conditions, all of them presented, in at least one of their annual/sustainability report, the highlights of their water security plan (which are also called "contingency plan").

Nevertheless, it is important to emphasize that only one company brought a separate section on their water security plan, indicating that this issue is not seen as rather relevant to stakeholders, on the water companies' understanding. In the same line, not a great number of reports (only seven companies from our sample) mentioned water security on their materiality matrix. Materiality analysis is a multi-purpose tool for prioritizing sustainability issues from the perspective of both company and stakeholders (Calabrese, Costa, Levialdi Ghiron, & Menichini, 2019) thus, the low score of this indicator shows that few stakeholders understand water security as a material factor for the business, or see it as a low potential risk for water utilities activities. It indicates also that stakeholders' perception regarding the need of designing actions to increase water scarcity resilience is not a priority.

Finally, only seven of the 15 analyzed companies present quantitative information of their water resources availability (like reservoir levels), an information that can facilitate stakeholders understanding the risk of water shortages. None of these companies presented this information in all the years in our analysis period.

5.4.7 Water availability prediction (WAP)

Creating preparedness in the water supply sector includes monitoring and forecasting water availability (Pinto et al., 2021). That is why we considered in the class of AP the indication of the use of (*i*) hydrological models and (*ii*) seasonal forecasting. Nine Brazilian companies mentioned the use of one or both methods, but the average score across the years was 67.5% lower than the maximum score for this class of indicators.

Mathematical models may be developed to manage uncertainty properties such as long-term risk, resilience, and vulnerability (Srdjevic, Srdjevic, & Lakicevic, 2018). It is not a simple task to develop such models, since those are complex approaches, that should consider emerging knowledge and computational tools to better incorporate information regarding vegetation, land cover and clouds movements (Getirana et al., 2021), among others. That is why most of the existing models representing climate change impacts are based on incomplete and imperfect knowledge, and there are no universal established parameters to define their quality, resulting in low trustiness by stakeholders (Srdjevic et al., 2018).

5.4.8 Demand-side infrastructure improvements (DSI)

Demand-side infrastructure improvements was the last class of factors in our rank, presenting the lowest relative score. It included the following improvements available for households: (*i*) household leakage reduction, (*ii*) water efficient equipment installment and fitting; (*iii*) water reuse and recycling, and (*iv*) rainwater harvesting.

Five companies did not mention either of the considered DSI and, all those that mentioned at least one, failed to discuss the DSI topic in all years with available reports. Additionally, some of the companies declared implementing actions to incentivize DSI for agricultural, industrial, and public users, but not to households, which was the focus of our research. These results may indicate either that Brazilian water companies are skeptical of the effectiveness of demand-side measures, or that Brazilian population does not hold a well-developed culture regarding demand-side infrastructure action as other places in the world, such as Australia, Asia, Europe and in the United States.

From the four items considered in DSI, "leakage reduction" was the most cited in reports, followed by "efficient equipment and fitting". Regarding the first item, leak repair by consumers was mentioned by one third of the companies in our sample (5 out of 15 companies). One may conclude that Brazil's biggest concerns regarding leakages remain on distribution networks rather than on household leakages. This is because Brazil still holds high levels of physical losses on the water systems networks (SNIS, 2022) and thus it is plausible that companies' efforts focus on these kinds of leakages. Regarding the second item, the most cited equipment in our sample was flow-control device, although in the literature there are other commonly used devices, such as dual-flush toilets, household appliances with lower water consumption and equipment for gray-water collection and use (Roshan & Kumar, 2020; Stone & Johnson, 2022).

Finally, only three companies mentioned rainwater harvesting and water recycling or reuse in their reports. More remarkable is that a great number of the companies mentioned using such practices in their own facilities or contributing to enhancing the use of such DSI in public buildings, such as schools, but not in households. These results reinforce the interpretation that, in Brazil, DSI is still not a commonly used practice or established culture.

5.5 CONCLUSIONS

In this article, we present the Total Water Security Index, compound by seven factors related to water security disclosure. This tool may be used to help water companies to adequately disclose water security issues and actions, as well as provide comparable information for these utilities' stakeholders to understand the degree to which water availability and uncertainties are being addressed.

Evaluating the annual/sustainability reports from 15 Brazilian water supply companies, from 2019 to 2022, we identified that water utilities are slowly increasing the topic disclosed, but still have important deficits when it comes to water security reporting. Water availability evaluation and prediction as well as demand-side infrastructure improvements are the aspects of water security receiving least attention by water utilities managers. Nevertheless, all other factors included in the TWSI could be improved to score better.

That result is rather paradoxical, since the impacts of global change, which includes the increase in the frequency and in the magnitude of extreme weather events, are becoming a bigger concern worldwide, year after year. The understanding of climate changes as a reality may be present in reports, but actions and plans to overcome its impacts must be clearer. Not giving the necessary attention to this issue means disregarding the fact that water, the core business of water utilities, will become increasingly scarce.

It is not entirely the utilities' fault. This industry's stakeholders may not have reached the maturity to understand the real severeness of such issues. Also, some cultural and political characteristics of the country may be factors still holding back real changes or more practical actions. Finally, there are also social and geographical characteristics in the operating areas of our sample that may indicate that a "one size fits all" approach will not be feasible. Nevertheless, improvements in all the analyzed reports are in fact needed.

6. CONCLUSIONS OF THE DESSERTATION

The objective of this dissertation was to offer subsidies to W&S utilities, local, regional, and national governments, as well as regulation agencies, for decision-making and strategy development, seeking to create resilience and guarantee the availability of water in the country. Considering such purpose, four articles were written: one literature review, two quantitative studies and one qualitative research, which are presented in the form of scientific articles, submitted or to be submitted for publication in specialized journals. Table 6.1 presents a summary of the main results and academic and managerial contributions of each of the studies conducted.

The conservation of water, although urgent, is not trivial. This dissertation showed that the consumption of this good is governed by the theory of consumer behavior, showing that preferences and restrictions, as well as the situation to which the individual is inserted and the level of information that reaches him/her, influence his consumption. Considering the scenario of climate change and the concrete possibility of water unavailability in upcoming years, it is necessary to use the situation to encourage a more rational use of this resource.

By what has been brought on Chapter 2, the factors that shape water consumption is considerably mingled. Therefore, it may not be a wise strategy to analyze each topic related to water consumption separately, as their relation is what determines water consumption behavior. This was the starting point for the design of the quantitative models from the studies presented on Chapters 3 and 4, as well as for the factors compounding the TWSI, designed on Chapter 5.

Table 6.1 – Summary of the results of each study conducted as part of this dissertation

Chapter/ Theme	Overall objective	Main results	Contributions
2. Systematic review of the literature	The study seeks to identify which factors influence household water consumption in the context of water scarcity.	• The factors that shape water consumption are considerably mingled • I present how these different kinds of factors interconnect and influence household water consumption. • The results show the importance of exploring differences in water demand-side management in the literature, from the country-of-origin perspective. • There is evidence of a need to encourage the development of studies in these developing countries, where the literature on this topic is scarce, but where actions to conserve drinking water resources are needed.	• The result motivates reflections regarding the many factors that may influence water consumption, and their relation. • Also, it demonstrates the gap regarding studies on water consumption in developing countries, highlighting the difficulty of such a group of countries to find evidence to be used when designing water conservation policies.
3. Utility Ownership	Seeks to help on the understand-ding if and to what extent the increase on the private sanitation market influences residential water saving attitudes	• On average, inhabitants living in municipalities where private companies operate consume less water than inhabitants supplied by public companies. • In municipalities with higher service indexes people tend to consume less water. • NRW index also has a negative and significant correlation to average per capita water consumption.	• Contributions to the dissertation: The results indicate the need of state-owned water providers, who are responsible for supplying more than 80% of the Brazilian population, to review their policies in water demand management, to decrease water consumption, using informational campaigns, encouraging voluntary saving behavior, and adopting economic incentives as well. In our analysis, one finding was that, along with ownership, other factors influenced water consumption in Brazil, which led to the research question for Article C.

Chapter/ Theme	Overall objective	Main results	Contributions
4. Non-revenue Water	To identify the main drivers of non-revenue water in Brazil, to elucidate the reasons why NRW increased in the past years in the country as well as to present potential actions to reverse this scenario	• Four of the ten factors considered, chosen from information on available literature, were statistically significant to explain NRW levels in Brazil: population size, share of residential consumers, network length and utility ownership. • We found a positive relation between urban population and NRW • The negative and significant correlation (at 5%) between the share of residential connections and NRW shows that a great non-revenue water in Brazil, from 2017 to 2021, came from non-residential connections. • Regarding network length, our results do not support the hypothesis that the existence of a wider area to be served by the supplier should be linked to higher levels of water losses. • GDP did not represent a significant variable to explain NRW variability in Brazil.	• Indication of Brazilian factors that contribute to water loss • Indication that the use of findings in the literature, that are usually based on data from developed countries, may have bias and not be applicable to the Brazilian reality.
5. Disclosing water security	The objective was to understand the degree of disclosed preparedness to face extreme events that may compromise water availability, and which are the most frequent and less frequent actions taken by water utilities aiming at such a goal.	• By presenting low average scores in the created index, we identified that water utilities still have important deficits when it comes to water security reporting. • On average, sustainability reports from water utilities score around 57.4% of the maximum TWSI score, meaning there is a considerable number of indicators regarding water security that water utilities do not include in their reporting. • The class of indicators with a score closer to the maximum was "user's awareness creation", which includes two indicators: (*i*) efficient water consumption through educational programs; and (*ii*) efficient water consumption through economic incentives. • Demand-side infrastructure improvements was the last class of factors in our rank, presenting the lowest relative score. It included the following improvements: (*i*) household leakage reduction, (*ii*) water efficient equipment installment and fitting; (*iii*) water reuse and recycling, and (*iv*) rainwater harvesting.	• We verified that Brazilian water companies do not give the necessary attention to water security, in the context of climate changes, even though water is becoming increasingly scarce.

Considering specifically the Brazilian reality, the W&S sector has been facing great changes recently. Such changes have consequences, and there should be a great effort to foresee such changes. The privatization process, under which the country is going through, should be understood, and the simple process of comparing this scenario to the one developed countries face is not a good idea. This is because some nations went through privatization processes decades ago, in times with different perspectives, economically, socially and, more important, sustainably. For instance, back then, climate changes were seen like a much more distant problem than it is today and influenced less people than today. That is why, the articles presented on Chapters 3, 4 and 5 considered specifically the Brazilian context.

The study presented on Chapter 3 indicates that ownership is as well a factor shaping water consumption, and a few possible explanations are presented. In the hierarchical linear model designed for the study, NRW showed to be a significant variable related to water consumption. Considering the scenario of high levels of NRW in Brazil, this result showed to be an interesting variable to be analyzed more deeply, and that was done in the study presented in Chapter 4.

Finally, since awareness, on the framework proposed on Chapter 2, is impacting many other factors that shape water consumption, it seemed like an interesting item to be explored more deeply, which motivated the study presented on Chapter 5.

An overall conclusion that may be brought from the results of the four articles is that there is currently a great gap between work carried out in developed countries and in developing ones, indicating that most recent and advanced solutions to water management do not apply to a great part of the nations, where water problems are considerably increasing and water supply systems may collapse. A great part of problems and solutions being studied by academics do not apply to a considerable part of the world's population, that may be considered "far behind". While an increasing number of articles carried out in developed countries discuss water rain harvesting for gardening, in a great part of the world millions of people still do not have access to drinking water. This dissertation presents many aspects of the Brazilian perspective, which may be considered for developing national strategies, both for public and for private companies.

This dissertation also brings a great number of treated data, extracted from SNIS, one of the world's most complete database on sanitation. The treatment I proposed seeks to eliminate inconsistencies, frequent in the SNIS database, since information for the database is provided by municipalities' administration without the appropriate review from the federal government or audit control from an independent third party. Despite these inconsistencies, the database is, overall, useful for studies. Using this database, from Brazil, may be a way of filling the gap mentioned before, once Brazil's reality may be closer to reality in many developing countries, which share similar economic, social, and urban development issues.

REFERENCES

Abu-Bakar, H., Williams, L., & Hallett, S. H. (2021). A review of household water demand management and consumption measurement. *Journal of Cleaner Production*, *292*, 125872. doi: 10.1016/j.jclepro.2021.125872

Adams, A. S., & Lutz Ley, A. N. (2012). An empirical study of factors affecting water loss in Mexican cities. *Journal of Water Sustainability*, *2*(3), 167-178.

Aegea (2020). *Relatório Annual de Sustentabilidade 2019*. São Paulo, SP: Aegea. Retrieved from: https://tinyurl.com/45cxbb9c.

Aegea (2022). *Annual Sustainability Report 2021*. São Paulo, SP: Aegea. Retrieved from: https://tinyurl.com/2x2d5yp6.

Ahmad, M. T., & Daura, H. A. (2019). Domestic water consumption under unimproved water supply in semi-arid region of northern Nigeria. *Sustainable Water Resources Management*, *5*, 415-424. doi: 10.1007/s40899-017-0177-5

Ajzen, I. (1991) The theory of planned behavior. *Organizational Behavior and Human Decision Processes*, *50*(2), 179-211. doi: 10.1016/0749-5978(91)90020-T.

Ajzen, I. (1991) The theory of planned behavior. *Organizational Behavior and Human Decision Processes*, *50*(2), 179-211. doi: 10.1016/0749-5978(91)90020-T.

Aldirawi S., Souter, R., & Beal, C. D. (2019). Barriers and opportunities for behavior change in managing high water demand in water scarce indigenous communities: An Australian perspective. *Journal of Water Sanitation and Hygiene for Development, 9*(4), 765–773. doi: 10.2166/washdev.2019.091.

Alsharif, K., Feroz, E. H., Klemer, A., Raab, R. (2008). Governance of water supply systems in the Palestinian Territories: a data envelopment analysis approach to the management of water resources. *Journal of Environmental Management*, *87*, 80-94.

Al-Zahrani, K., Baig, M., & Straquadine, G. (2013). Consumption behavior and water demand management in the Kingdom of Saudi Arabia: Implications for extension and education. *Arab Gulf Journal of Scientific Research*, *31*(2/3), 79-89. doi: 10.51758/AGJSR-2/3-2013-0008.

Amaral, A, L., Martins, R., Dias, L. C. (2023). Drivers of water utilities' operational performance: An analysis from the Portuguese case. *Journal of Cleaner Production*, *389*. doi: 10.1016/j.jclepro.2023.136004

ANA – Agência Nacional de Águas e de Saneamento Básico (2021a). *Monitor de Secas*. Retrieved from: https://monitordesecas.ana.gov.br/mapa?mes=8&ano=2021.

ANA – Agência Nacional de Águas e de Saneamento Básico (2021b). *Atlas águas: segurança hídrica do abastecimento urbano*. Brasília, DF: ANA.

ANA – Agência Nacional de Águas e de Saneamento Básico (2023). *Conjuntura dos recursos hídricos no Brasil 2022: informe anual*. Brasília, DF: ANA.

Arbues, F., & Barberan, R. (2004). Price impact on urban residential water demand: A dynamic panel data approach. *Water Resources Research, 40*, W11402. Retrieved from: https://ron-griffin.tamu.edu/x677/readings/ArbuesBarberanVillanua.pdf.

Aria, M., & Cuccurullo, C. (2017). Bibliometrix: An R-tool for comprehensive science mapping analysis. *Journal of Informetrics*, *11*, 959-975. doi: 10.1016/j.joi.2017.08.007

Arnell, N. W., & Delaney, E. K. (2006). Adapting to climate change: Public water supply in England and Wales. *Climatic Change*, *78*: 227-255. doi: 10.1007/s10584-006-9067-9

Arsesp – Agência Reguladora de Saneamento e Energia do Estado de São Paulo (2020). *Metodologia e cálculo do nível econômico de perdas – Determinação da meta regulatória de perdas para a 3ª revisão tarifária ordinária da Sabesp*. (Final Technical Report n. 0064-2020). São Paulo, SP: Arsesp. Retrieved from: http://www.arsesp.sp.gov.br/ConsultasPublicasBiblioteca/NTF-0064-2020.pdf.

Barbosa, A., & Brusca, I. (2015) Governance structures and their impact on tariff levels of Brazilian water and sanitation corporations. *Utilities Policy*, *34*, 94-105. doi: 10.1016/j.jup.2015.02.002

Beal, C. D., Gurng, T. R., & Stewart, R. A. (2016). Demand-side management for supply-side efficiency: Modelling tailored strategies for reducing peak residential water demand. *Sustainable Production and Consumption*, *6*, 1-11. doi: 10.1016/j.spc.2015.11.005

Beecher, J. A., & Kalmbach, J. A. (2013). Structure, regulation, and pricing of water in the United States: A study of the Great Lakes region. *Utilities Policy*, *24*, 32-47. doi: 10.1016/j.jup.2012.08.002

Beker, B. A., & Kansal, M. L. (2023). Complexities of the urban drinking water systems in Ethiopia and possible interventions for sustainability. *Environment, Development and Sustainability*. doi: 10.1007/s10668-022-02901-7

Bennett, A. F., Nimmo, D. G., & Radford, J. Q. (2014). Riparian vegetation has disproportionate benefits for landscape-scale conservation of woodland birds in highly modified environments. *Journal of Applied Ecology*, *51*(2), 514-523. doi: 10.1111/1365-2664.12200

Bernardo, V., Fageda, X & Termes, M. (2015) Do droughts have long-term effects on water consumption? Evidence from the urban area of Barcelona. *Applied Economics, 47(48):* 5131-5146. DOI: 10.1080/00036846.2015.1042147.

Biswas, A., & Gangwar, D. (2021). Studying the water crisis in Delhi due to rapid urbanization and land use transformation. *International Journal of Urban Sustainable Development*, *13*(2), 199-213. doi: 10.1080/19463138.2020.1858423

Braadbaart, O. (2002). Private versus public provision of water services: does ownership matter for utility efficiency?. *Journal of Water Supply Research and Technology - Aqua*, *51*(7), 375-388. doi: 10.2166/aqua.2002.0034

Brelsford, C., & Abbott, J. K. (2017). Growing into water conservation? Decomposing the drivers of reduced water consumption in Las Vegas, NV. *Ecological Economics*, *133*, 99-110. doi: 10.1016/j.ecolecon.2016.10.01

Britto, A. L. N. de P., Lima, S. C. R. B. D., Heller, L., & Cordeiro, B. D. S. (2012). Da fragmentação à articulação: a política nacional de saneamento e seu legado histórico. *Revista Brasileira de Estudos Urbanos e Regionais*, *14*(1), 65. doi: 10.22296/2317-1529.2012v14n1p65.

Bursztyn, M., & Bursztyn, M. A. (2012). *Fundamentos de política e gestão ambiental: os caminhos do desenvolvimento sustentável*. Rio de Janeiro, RJ: Garamond.

Calabrese, A., Costa, R., Levialdi Ghiron, N., & Menichini, T. (2019). Materiality analysis in sustainability reporting: A tool for directing corporate sustainability towards emerging economic, environmental and social opportunities. *Technological and Economic Development of Economy*, *25*(5), 1016-1038. doi: 10.3846/tede.2019.10550

Cantele, S., Tsalis, T. A., & Nikolaou, I. E. (2018). A New Framework for Assessing the Sustainability Reporting Disclosure of Water Utilities. *Sustainability*, *10*, 433. doi: 10.3390/su10020433

Carvalho, A. E. C., & Sampaio, L. M. B. (2015). Paths to universalize water and sewage services in Brazil: The role of regulatory authorities in promoting efficient service. *Utilities Policy, 34*: 1-10. doi: 10.1016/j.jup.2015.03.001

Carvalho, P., Pedro, I., Cunha Marques, R. (2015). The most efficient clusters of Brazilian water companies. *Water Policy*, *17*: 902–917. doi: 10.2166/wp.2015.148

Cetrulo, T. B., Ferreira, D. F. C., Marques, R. C., & Malheiros, T.F. (2020). Water utilities performance analysis in developing countries: On an adequate model for universal access. *Journal of Environmental Management*, *268*: 110662. doi: 10.1016/j.jenvman.2020.110662

Companhia Catarinense de Águas e Saneamento – CASAN. *Relatório anual de sustentabilidade 2020*. Florianópolis: CASAN, 2021. Retrieved from: https://ri.casan.com.br/wp-content/uploads/2021/12/Relat%C3%B3rio-de-Sustentabilidade-2020-CASAN-5.pdf.

Companhia de Saneamento do Pará – Sanepar (2023). *Relato integrado 2022*. Curitiba, PR: Saneago. Retrieved from: https://ri.sanepar.com.br/docs/Sanepar-2022-12-31-jRKTNpcT.pdf.

Companhia Pernambucana de Saneamento – Compesa (2021). *Relatório de sustentabilidade 2021*. Recife, PE: Compesa. Retrieved from: https://servicos.compesa.com.br/wp-content/uploads/2021/04/Relatorio-de-Sustentabilidade-2021-v2.pdf.

Corral-Verdugo, V., Bechtelb, R.B., & Fraijo-Sing, B. (2003) Environmental beliefs and water conservation: An empirical study. *Journal of Environmental Psychology 23*, 247–257.

Cuartas, L. A., Cunha, A. P. M. D. A., Alves, J. A., Parra, L .M. P., Deusdará-Leal, K., Costa, L. C. O …. Marengo, J. A. (2022). Recent hydrological droughts in Brazil and their impact on hydropower generation. *Water*, *14*(4), 601. doi: 10.3390/w14040601

Cunha, A. P. M. A., Zeri, M., Leal, K. D., Costa, L., Cuartas, L. A., Marengo, J. A.,… Ribeiro-Neto, G. (2019). Extreme drought events over Brazil from 2011 to 2019. *Atmosphere, 10*(642). doi:10.3390/atmos10110642

Dalhuisen, J. M., Florax, R. J. G. M., De Groot, H. L. F., & Nijkamp, P. (2003). Price and income elasticities of residential water demand: A meta-analysis. *Land Economics*, *79*(2), 292-308. doi: 10.2307/3146872

Damodaran, K. (2011). Household water consumption pattern in Cuddalore District, Tamil Nadu. *International Journal of Regulation and Governance*, *11*(2), 113-128. doi: 10.3233/IJR-120105

De Oliveira, L. M., Da Silva, S. M. O., Souza Filho, F. A., Carvalho, T. M. N., & Frota, R. L. (2020). Forecasting urban water demand using cellular automata. *Water*, 12, 2038. doi:10.3390/w12072038

De Santi, A. D., Cetrulo, T. B., & Malheiros, T. F. (2021). Water loss control practices in developing countries: A case study of a Brazilian region. *Water Supply*, *21*(2). doi: 10.2166/ws.2020.351

Deliberação Arsesp n. 469. (2014, February 03). Aprova, em caráter emergencial, a implantação do Programa de Incentivo à Redução de Consumo de Água da Sabesp. São Paulo, SP: Agência Reguladora de Saneamento e Energia do Estado de São Paulo.

Demertzidis, N., Tsalis, T. A., Loupa, G., & Nikolaou, I. E. (2015). A benchmarking framework to evaluate business climate change risks: A practical tool suitable for investors decision-making process. *Climate Risk Management*, *10*: 95-105. doi: 10.1016/j.crm.2015.09.002

Downing, T. E., Butterfield, R. E., Edmonds, B., Knox, J. W., Moss, S., Piper, B. S., & Weatherhead, E. K. (2003). *CCDeW: climate change and demand for water*. Oxford, England: Stockholm Environment Institute.

Dupré, L. (1994). The common good and the open society. In Douglas, R.B., & Hollenbach, D. (Eds), *Catholicism and Liberalism* (pp. 172-95). Cambridge: Cambridge University Press.

Echeverría, J. M. A. (2020). Cross-country evidence for social dimensions of urban water consumption during droughts. *Cleaner Production*, 260, 120895. doi: 10.1016/j.jclepro.2020.120895

Edirisinghe, R. D., & Pathirana, S. (2021). Reduction potential of potable water consumption at urban households: a case study in Sri Lanka. *Environment, Development and Sustainability*, *23*: 13689–13706. doi: 10.1007/s10668-021-01234-1.

Einhorn, H. J., & Hogarth, R. M. (1981). Behavioral decision theory: Processes of judgment and choice. *Annual Review of Psychology, 32*, 53-88.

EMBASA – Empresa Baiana de Saneamento (2020). *Relatório da administração, sustentabilidade e demonstrações financeiras*. Salvador, BA: EMBASA. Retrieved from: https://www.embasa.ba.gov.br/a-embasa/responsabilidade-socioambiental/relatorio-de-administracao-e-sustentabilidade.

Ferasso, M., Bares, L., Ogachi, D., & Blanco, M. (2021). Economic and sustainability inequalities and water consumption of European Union Countries. *Water*, *13*(19), 2696. doi: 10.3390/w13192696

Ferro, G., Lentini, E. J., Mercadier, A. C., & Romero, C. A. (2014). Efficiency in Brazil's water and sanitation sector and its relationship with regional provision, property and the independence of operators. *Utilities Policy*, *28*, 42-51

García-Valiñas, M. A., González-Gómez, F., & Picazo-Tadeo, A. J. (2013). Is the price of water for residential use related to provider ownership? Empirical evidence from Spain. *Utilities Policy*, *24*, 59-69.

Gasson, C. (2023, 10 August). How will we pay for water security?. *Global Water Intelligence*. Retrieved from: https://www.globalwaterintel.com/news/2023/32/how-will-we-pay-for-water-security?.

Gaur, A., & Kumar, M. (2018). A systematic approach to conducting review studies: an assessment of content analysis in 25 years of IB research. *Journal of World Business*, *53*, 280-289. doi: 10.1016/j.jwb.2017.11.003

Getirana, A., Libonati, R., & Cataldi, M. (2021). Brazil is in water crisis – it needs a drought plan. *Nature*, 600, 218-220. doi: 10.1038/d41586-021-03625-w

Gilbertson, M., Hurlimann, A., & Dolnicar, S. (2011). Does water context influence behavior and attitudes to water conservation?. *Australasian Journal of Environmental Management*, *18*(1), 47-60.

Gómez-Llanos, E., Durán-Barroso, C., & Robina-Ramírez, R. (2020). Analysis of consumer awareness of sustainable water consumption by the water footprint concept. *Science of The Total Environment*, *721*, 37743. doi: 10.1016/j.scitotenv.2020.137743

González, E., Felipe-Lucia, M. R., Bourgeois, B., Boz, B., Nilsson, C., Palmer, G., & Sher, A. A. (2017). Integrative conservation of riparian zones. *Biological Conservation,* 211(B), 20-29. doi: 10.1016/j.biocon.2016.10.035

González-Gómez, F., García-Rubio, M. A., & Guardiola, J. (2011). Why Is Non-revenue Water So High in So Many Cities*?*. *International Journal of Water Resources Development, 27*(2), 345-360.

González-Gómez, F., Martínez-Espiñeira, R., García-Valiñas, M. A., & García-Rubio, M. A. (2012). Explanatory factors of urban water leakage rates in Southern Spain. *Utilities Policy, 22*, 22-30. doi: 10.1016/j.jup.2012.02.002.

Grover, D., & Lucinda C. R. (2021). An Evaluation of the Policy Response to Drought in the City of São Paulo, Brazil: An Election Cycle Interpretation of Effectiveness. *The Journal of Development Studies*, *57*(3), 365-382. doi: 10.1080/00220388.2020.1786061

Hahn, R., & Kühnen, M. (2013). Determinants of sustainability reporting: a review of results, trends, theory, and opportunities in an expanding field of research. *Journal of Cleaner Production*, *59*, 5-21. doi: 10.1016/j.jclepro.2013.07.005

Hair, J. F. Jr., & Fávero, L. P. (2019). Multilevel modeling for longitudinal data: concepts and applications. *RAUSP Management Journal 54*(4), 459-489. doi: 10.1108/RAUSP-04-2019-0059

Hall, R. E., & Papell, D. H. (2005). *Macroeconomics*. New York, NY: W. W. Norton & Company.

Hardin, G. (1968). *The Tragedy of Commons*. *Science*, *162*(3859), 1243-1248.

Heller, L. (2007). Basic sanitation in Brazil: Lessons from the past, opportunities from the present, challenges for the future. *Journal of Comparative Social Welfare*, *23*(2), 141-153. doi: 10.1080/17486830701494640

Hellwig, M., & Polk, A. (2021). Do political links influence water prices? Determinants of water prices in Germany. *Utilities Policy*, *70*. doi: 10.1016/j.jup.2021.101184

Hochstrat, R., Wintgens, T., Kazner, C., Melin, T., & Gebel, J. (2010). Options for water scarcity and drought management: The role of desalination. *Desalination and Water Treatment*, *28*, 96-102. doi: 10.5004/dwt.2010.1347

Hodges, H., Huehl, C., Andreson, S.E., Ehret, P.J. & Brick, C. (2020) How Managers Can Reduce Household Water Use Through Communication: A Field Experiment. *Journal of policy analysis and management, 39(4)*: 1076-1099. DOI: https://doi.org/10.1002/pam.22246.

Homsy, G. C., & Warner, M. E. (2020). Does public ownership of utilities matter for local government water policies?. *Utilities Policy*, *64*. doi: 10.1016/j.jup.2020.101057

Hoppin, K. B., & Meshes, E. (2022). Saving the water in California: A call for behavior analytic action. *Behavior and Social Issues*, *31*, 437-450. doi: 10.1007/s42822-022-00108-z

Hunt, D. V. L., & Rogers, C. D. F. (2014). A benchmarking system for domestic water use. *Sustainability*, *6*, 2993-3018. doi:10.3390/su6052993

Hunt, D. V. L., & Shahab, Z. (2021). Sustainable water use practices: Understanding and awareness of master's level students. *Sustainability*, *13*(19), 10499. doi: 10.3390/su131910499

Hunt, J. D, Stilpen, D., & Freitas, M. A. V. (2018). A review of the causes, impacts and solutions for electricity supply crises in Brazil. *Renewable and Sustainable Energy Reviews*, *88*. doi: 10.1016/j.rser.2018.02.030

Ibáñez-Rueda, N., Guardiola, J., & González-Gómez, F. (2021). The role of nature contact and connectedness to nature as determinants of household water use: A case study from Spain. *Water Environmental Journal*, *36*, 282-291. doi: 10.1111/wej.12765

Ibrahim, A, S., Knox, K., Rundle-Thiele, S., Arli, D. (2018) Segmenting a Water Use Market: Theory of Interpersonal Behavior Insights. *Social Marketing Quarterly, 24*(1): 3-17. DOI: 10.1177/1524500417741277

Ibrahim, A. S., Memon, F. A., & Butler, D. (2021). Seasonal Variation of Rainy and Dry Season Per Capita Water Consumption in Freetown City Sierra Leone. *Water*, *13*(4), 499. doi: 10.3390/w13040499

IFC – International Finance Corporation (2013). *Manual for performance-based contracting by water utility companies in Brazil*. Mexico: IFC. Retrieved from: https://tinyurl.com/ykjpz3yk.

Inman, D., & Jeffrey, P. (2006). A review of residential water conservation tool performance and influences on implementation effectiveness. *Urban Water Journal*, *3*(3), 127-143. doi: 10.1080/15730620600961288

Ioannou, A. E., Creaco, E. F., & Laspidou, C. S. (2021). Exploring the effectiveness of clustering algorithms for capturing water consumption behavior at household level. *Sustainability*, *13*(5), 2603. doi: 10.3390/su13052603

IPCC – International Panel on Climate Change (2021). Summary for policymakers. In V. Masson-Delmotte, P. Zhai, A. Pirani, S. L. Connors, C. Péan, S. Berger, … B. Zhou (Eds.), *Climate Change 2021: The Physical science basis – contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge, CA: Cambridge University Press.

IPCC – International Panel on Climate Change (2022). Summary for Policymakers. In H.-O. Pörtner, D. C. Roberts, E. S. Poloczanska, K. Mintenbeck, M. Tignor, A. Alegría … A. Okem (Eds.). *Climate Change 2022: Impacts, Adaptation, and Vulnerability. Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge, CA: Cambridge University Press.

Ito, Y., Kobayashi, Y., Yokomichi, H., Malla, S. S., Kiem, A. S., & Nishida, K. (2021). Physical and non-physical factors associated with water consumption at the household level in a region using multiple water sources. *Journal of Hydrology: Regional Studies*, *37*, 100928. doi: 10.1016/j.ejrh.2021.100928

Jethoo, A. S., & Poonia, M. P. (2011). Water Consumption Pattern of Jaipur City (India). *International Journal of Environmental Science and Development*, *2*(2), 152-155. doi: 10.7763/IJESD.2011.V2.114

Kallis, G., Ray, I., Fulton, J., & McMahon, E. (2010). Public versus private: Does it matter for water conservation? Insights from California. *Environmental Management*, *45*, 177-191. doi: 10.1007/s00267-009-9403-8

Khan, S. J., Deere, D., Leusch, F. D., Humpage, A., Jenkins, M., & Cunliffe, D. (2015). Extreme weather events: Should drinking water quality management systems adapt to changing risk profiles? *Water Resources*, *85*, 124-136. doi: 10.1016/j.watres.2015.08.018

Khan, S. J., Deere, D., Leusch, F. D., Humpage, A., Jenkins, M., Cunliffe, D, Fitzgerald, S. & Stanford, B. D. (2017). Lessons and guidance for the management of safe drinking water during extreme weather events. *Environmental Science: Water Research & Technology*, *3*(2), 262-277. doi: 10.1039/c6ew00165c

Kingdom, B., Liemberger, R., & Marin, P. (2006). The challenge of reducing non-revenue water (NRW) in developing countries how the private sector can help: A look at performance-based service contracting. (Water supply and sanitation board discussion paper series, paper n. 8). Washington, DC: The World Bank.

Klewitz, J., & Hansen, E. G. (2014). Sustainability-oriented innovation of SMEs: A systematic review. *Journal of Cleaner Production*, *65*, 57-75. doi: 10.1016/j.jclepro.2013.07.017

Kolstad, C. D. (2011). *Environmental Economics*. Oxford, UK: Oxford Press.

Koop, S. H. A., Van Dorssen, A. J., & Brouwer, S. (2019). Enhancing domestic water conservation behaviour: A review of empirical studies on influencing tactics. *Journal of Environmental Management*, *247*, 867-876. doi: 10.1016/j.jenvman.2019.06.126.

Kooperman, G. J., Chen, Y., Hoffman, F. M., Koven, C. D., Lindsay, K., Pritchard, M. S., Swann, A. L. S., & Randerson, J. T. (2018). Forest response to rising CO_2 drives zonally asymmetric rainfall change over tropical land. *Nature Climate Change*, *8*: 434-440. doi: 10.1038/s41558-018-0144-7

Kumar, M., Sharma, A., Tabhani, N., & Otaki, Y. (2021). Indoor water end-use pattern and its prospective determinants in the twin cities of Gujarat, India: Enabling targeted urban water management strategies. *Journal of Environmental Management*, *288*, 112403. doi: 10.1016/j.jenvman.2021.112403

Larrinaga-González, C., & Pérez-Chamorro, V. (2008). Sustainability accounting and accountability in public water companies. *Public Money & Management*, *28*(6), 337-343. doi: 10.1111/j.1467-9302.2008.00667.x

Larson, K. L., Wutich, A., White, D., Munoz-Erickson, T. A., & Harlan, S. L. (2011). Multifaceted perspectives on water risks and policies: A cultural domains approach in a southwestern city. *Human Ecology Review*, *18*(1), 75-87. Retrieved from: https://www.jstor.org/stable/24707688.

Lei n. 11.445. (January 5, 2007). Estabelece as diretrizes nacionais para o saneamento básico; cria o Comitê Interministerial de Saneamento Básico … Brasília, DF: Brasil.

Lei n. 14.026, de 15 de julho de 2020. Atualiza o marco legal do saneamento básico e altera a Lei nº 9.984, de 17 de julho de 2000, para atribuir à Agência Nacional de Águas e Saneamento Básico (ANA) competência para editar normas de referência sobre o serviço de saneamento, a Lei nº 10.768, de 19 de novembro de 2003, para alterar o nome e as atribuições do cargo de Especialista em Recursos Hídricos… Brasília, DF: Brasil.

Lei n. 14.026. (June 15, 2020). Estabelece as diretrizes nacionais para o saneamento básico; cria o Comitê Interministerial de Saneamento Básico; altera as Leis n os 6.766, de 19 de dezembro de 1979, 8.666, de 21 de junho de 1993, e 8.987, de 13 de fevereiro de 1995; e revoga a Lei nº 6.528, de 11 de maio de 1978. Brasília, DF: Brasil.

Lei n. 8.987. (February 13, 1995). Dispõe sobre o regime de concessão e permissão da prestação de serviços públicos previsto no art. 175 da Constituição Federal, e dá outras providências. Brasília, DF: Brasil.

Liemberger, R., & Wyatt, A. (2019). Quantifying the global non-revenue water problem. *Water Supply*, *19*(3)*,*831-837.

Lindsay, J., & Supski, S. (2017). Changing household water consumption practices after drought in three Australian cities. *Geoforum*, *84*, 51-58. doi: 10.1016/j.geoforum.2017.06.001

Littlefair, K. (1998). *Willingness to pay for water at household level: individual financial responsibility for water consumption MEWEREW Occasional paper No.26, Water Issue Study Group, School of Oriental and African Studies (SOAS*), University of London, London, *UK*, 46p.

Liu, J., Yang, H., Gosling, S. N., Kummu, M., Flörke, M., Pfister, S., … Oki, T. (2017). Water scarcity assessments in the past, present, and future. *Earth's Future*, *5*, 545-559. doi: 10.1002/2016EF000518

Loch, A., Adamson, D., & Mallawaarachchi, T. (2014). Role of hydrology and economics in water management policy under increasing uncertainty. *Journal of Hydrology*, *518*: 5-16. doi: 10.1016/j.jhydrol.2013.10.049

Lowe, B., Lynch, D., & Lowe, J. (2014). The role and application of social marketing in managing water consumption: A case study. *International Journal of Nonprofit and Voluntary Sector Marketing*, *19*, 14-26. doi: 10.1002/nvsm.1484

Lucas, N.P. & Cordery, I. (2019) Effects of heightened price awareness on urban water consumption. *Australasian Journal of Water Resources, 23(2)*: 129-136. DOI: 10.1080/13241583.2019.1650588

Magnusson, T. S. (2004). Household responsiveness to water demand management incentives in Windhoek, Namibia. *Water Policy*, *6*(5), 453-471. doi: 10.2166/wp.2004.0030

Mankad, A., Walton, A., & Gardner, J. (2019). Psychological predictors of public acceptance for urban stormwater reuse. *Journal of Hydrology*, *572*, 414-421. doi: 10.1016/j.jhydrol.2019.03.018

March, H., Hernández, M., & Saurí, D. (2015). Assessing domestic water use habits for more effective water awareness campaigns during drought periods: A case study in Alicante, eastern Spain. *Natural Hazards and Earth System Sciences*, *15*, 963-972. doi: 10.5194/nhess-15-963-2015

March, H., Perarnau, J., & Saurí, D. (2012). Exploring the links between immigration, ageing and domestic water consumption: The case of the metropolitan area of Barcelona. *Regional Studies*, *46*(2), 229-244. doi: 10.1080/00343404.2010.487859

Margulies, B. N. (2018). *Desempenho das empresas de saneamento básico brasileiras: uma análise dos setores público e privado* (Master's Thesis, Universidade de São Paulo). Retrieved from www.teses.usp.br.

Marin, P. (2009). Public-Private partnerships for urban water utilities: A review of experiences in developing countries. (World Bank Report). Washington, DC: World Bank.

Marques, E., & Saraiva, C. (2017). Urban integration or reconfigured inequalities? Analyzing housing precarity in São Paulo, Brazil. *Habitat International., 69*, 18-26. doi: 10.1016/j.habitatint.2017.08.004

Marques, R. C., & Simões, P. (2020). Revisiting the Comparison of Public and Private Water Service Provision: An Empirical Study in Portugal. *Water*, *12*, 1477. doi: 10.3390/w12051477

Marques, R. C., Da Cruz, N. F., & Pires, J. (2015). Measuring the sustainability of urban water services. *Environmental Science and Policy*, *54*: 142-151. doi: 10.1016/j.envsci.2015.07.003

Martínez-Espiñeira, R., & García-Valiñas, M.A. (2013). Adopting versus adapting: Adoption of water-saving technology versus water conservation habits in Spain. *International Journal of Water Resources Development*, *29*(3), 400-414. doi: 10.1080/07900627.2012.721695

Martínez-Espiñeira, R., García-Valiñas, M. A., & González-Gómez, F. (2009). Does private management of water supply services really increase prices? An empirical analysis. Urban Studies, *46*(4), 923-945. doi: 10.1177/0042098009102135

Martins, R., Antunes, M., & Fortunato, A. (2020). Regulatory changes to Portugal's social tariffs: Carrying water in a sieve?. *Utilities Policy*, *64*, 101038. doi: 10.1016/j.jup.2020.101038

Maziotis, A., Villegas, A., Molinos-Senante, M., & Sala-Garrido, R. (2020). Impact of external costs of unplanned supply interruptions on water company efficiency: Evidence from Chile. *Utility Policy*, *66*. doi: 10.1016/j.jup.2020.101087

Mesmer-Magnus, J., Viswesvaran, C., & Wiernik, B. M. (2012). The role of commitment in bridging the gap between organizational sustainability and environmental sustainability. In S. E. Jackson, D. S. Ones, & S. Dilchert (Eds.), *Managing HR for environmental sustainability* (pp. 155–186). San Francisco, CA: Jossey-Bass/Wiley.

Michael, R. T., & Becker, G. S. (1973). On the new theory of consumer behavior. *The Swedish Journal of Economics, 75*(4), 378-396. Retrieved from: http://www.jstor.org/stable/3439147.

Michelon, G., Pilonato, S. & Ricceri, F. (2015). CSR reporting practices and the quality of disclosure: An empirical analysis. *Critical Perspectives on Accounting*, 33, 59-78. doi: 10.1016/j.cpa.2014.10.003

Milne, M. J., & Adler, R. W. (1999). Exploring the reliability of social and environmental disclosures content analysis. *Accounting, Auditing & Accountability Journal, 12*(2), 237-256.

Mini, C., Hogue, T. S., & Pincetl, S. (2014). Estimation of residential outdoor water use in Los Angeles, California. *Landscape and Urban Planning*, *127*, 124-135. doi: 10.1016/j.landurbplan.2014.04.007

Mugabi, J., Kayaga, S., Njiru, C. (2007) Strategic planning for water utilities in developing countries. *Utilities Policy 15*: 1 – 8. doi:10.1016/j.jup.2006.10.001

Molinos-Senante, M., Marques, R. C., Pérez, F., Gómez, T., Sala-Garrido, R. & Caballero, R. (2016). Assessing the sustainability of water companies: A synthetic indicator approach. *Ecological Indicators*, *61*: 577-587.

Mongeon, P., & Paul-Hus, A. (2016). The journal coverage of Web of Science and Scopus: A comparative analysis. *Scientometrics*, *106*, 213-228. doi: 10.1007/s11192-015-1765-5

Moy, C. (2012). Rainwater tank households: Water savers or water users?. *Geographical Research*, *50*(2), 204-216. doi: 10.1111/j.1745-5871.2011.00720.x

Navarrete, S. D. S., Borini, F. M., & Avrichir, I. (2020). Environmental upgrading and the United Nations Sustainable Development Goals. *Journal of Cleaner Production*, *264*. doi: 10.1016/j.jclepro.2020.121563

Ociepa, E., Mrowiec, M., & Deska, I. (2019). Analysis of water losses and assessment of initiatives aimed at their reduction in selected water supply systems. *Water*, *11*, 1037. doi: 10.3390/w11051037

Oki, T., & Quiocho, R. E. (2020). Economically challenged and water scarce: Identification of global populations most vulnerable to water crises. *International Journal of Water Resources Development*, *36*(2/3), 416-428. doi: 10.1080/07900627.2019.1698413

Oliveira, G., & Ferreira, A. V. (2021). *Nem negacionismo nem apocalipse – economia do meio ambiente: uma perspectiva brasileira*. São Paulo, SP: BEI Editora.

Oliveira, G., Scazufca, P., & Sayon, P. L. (2022). *Estudo de perdas de água do Instituto Trata Brasil de 2022 (SNIS2020), desafios para disponibilidade hídrica e avanço da eficiência do saneamento básico no Brasil*. Retrieved from: https://tratabrasil.org.br/wp-content/uploads/2022/09/Relatorio_Completo.pdf.

Olmstead, S. M. (2010). The economics of managing scarce water resources. *Review of Environmental Economics and Policy, 4*(2), 179-188.

Olmstead, S. M., & Stavins, R. N. (2009). Comparing price and nonprice approaches to urban water conservation. *Water Resources Research 45*(4), 1-10. doi: 10.1029/2008WR007227

Olmstead, S. M., Hanemann, W. M. & Stavins R. N. (2007). Water demand under alternative price structures. *Journal of Environmental Economics and Management*, *54*, 181-198. doi: 10.1016/j.jeem.2007.03.002

Ong, C. & Araral, E. (2021) Using a Serious Digital Game to Communicate Drought Risk in Singapore: An Experimental Study. Environment and behavior, 54(2). DOI: ttps://doi.org/10.1177/0013916521103119.Ostad-Ali-Askar, K., Su, R., & Liu, L. (2018). Editorial: Water resources and climate change. *Journal of Water and Climate Change*, *9*(2). doi: 10.2166/wcc.2018.999

Papoutsi, A., & Sodhi, M. S. (2020). Does disclosure in sustainability reports indicate actual sustainability performance?. *Journal of Cleaner Production*, *260*, 121049. doi: 10.1016/j.jclepro.2020.121049

Pazzi, S., Tortosa-Ausina, E., Duygun, N., & Zambelli, S. (2016). The cost efficiency of water utilities: When does public ownership matter?. *Local Government Studies*, *42*(6), 980-1003. doi: 10.1080/03003930.2016.1207630

Peda, P., Grossi, G., Link, M. (2013). Do ownership and size affect the performance of water utilities? Evidence from Estonian municipalities. *Journal of Management and Governance*, *17*, 237-259. doi: 10.1007/s10997-011-9173-6

Pérard, E. (2009). Water supply: Public or private? An approach based on cost of funds, transaction costs, efficiency and political costs. *Policy and Society*, *27*(3): 193-219.

Pereira, M. A., & Marques, R. C. (2022). Technical and scale efficiency of the Brazilian Municipalities' water and sanitation services: A two-stage data envelopment analysis. *Sustainability*, *14*, 199. doi: 10.3390/su14010199.

Picazo-Tadeo, A. J., González-Gómez, F., & Sáez-Fernández, F. J. (2009). Accounting for operating environments in measuring water utilities' managerial efficiency. *The Service Industries Journal, 29*, 761-773. doi: 10.1080/02642060802190300

Pickering, C., & Byrne, J. (2014). The benefits of publishing systematic quantitative literature reviews for PhD candidates and other early-career researchers. *Higher Education Research & Development*, *33*, 534-548. 10.1080/07294360.2013.841651

Piffer, P. R., Tambosi, L. R., & Uriarte, M. (2022). Achieving sustainable water and land use systems in highly developed tropical landscapes. *Environmental Research Letters*, *17*. doi: 10.1088/1748-9326/ac8ab6

Pigou, A. C. (2013). *The Economics of Welfare*. London, United Kingdom: Palgrave Macmillian.

Pillot, J., Catel, L., Renaud, E., Augeard, B., & Roux, P. (2016). Up to what point is loss reduction environmentally friendly?: The LCA of loss reduction scenarios in drinking water networks. *Water Research*, *104*, 231-241.

Pindyck, R. S., & Rubinfeld, D. L. (2013). *Microeconomics*. Hoboken, NJ: Prentice Hall.

Pinto, F. S., Carvalho, B., & Marques, R. C. (2021). Adapting water tariffs to climate change: Linking resource availability, costs, demand, and tariff design flexibility. *Journal of Cleaner Production*, *290*. doi: 10.1016/j.jclepro.2021.125803

Pitz, G. F., & Sachs, N. J. (1984). Judgment and decision: Theory and application. *Annual Review of Psychology*, *35*(1),139-164.

Quesnel, K. J., & Ajami, N. K. (2017). Changes in water consumption linked to heavy news media coverage of extreme climatic events. *Science Advances*, *3*(10), e1700784. doi: 10.1126/sciadv.1700784

Radonic, L. (2019). Re-conceptualising water conservation: Rainwater harvesting in the desert of the southwestern United States. *Water Alternatives*, *12*(2), 699-714.

Rahim, S., Nguyen, K. A., Stewart, R. A., Ahmed, T., Giurco, D., & Blumenstein, M. (2021). A clustering solution for analyzing residential water consumption patterns, *233*, 107522. doi: 10.1016/j.knosys.2021.107522

Ramsey, E., Berglund, E. Z., & Goyal, R. (2017). The impact of demographic factors, beliefs, and social influences on residential water consumption and implications for non-price policies. *Water*, *9*(844), 1-21. doi: 10.3390/w9110844

Raudenbush, S., & Bryk, A. (2002). *Hierarchical linear models: Applications and data analysis methods*. Thousand Oaks, CA: Sage Publications.

Ravallion, M. (2002). On the urbanization of poverty. *Journal of Development Economics*, *68*(2): 435-442.

Rees, P., Clark, S., & Nawaz, R. (2020). Household forecasts for the planning of long-term domestic water demand: Application to London and the Thames Valley. *Population, Space and Place*, *26*(2), 2288. doi: 10.1002/psp.2288

Renwick. M. E., & Green, R. D. (2000). Do residential water demand side management policies measure up? An analysis of eight California water agencies. *Journal of Environmental Economics and Management*, *40*(1), 37-55. doi: 10.1006/jeem.1999.1102

Renzetti, S. (1992). Evaluating the welfare effects of reforming municipal water prices. *Journal of Environmental Economics and Management*, *22*, 147-163.

Renzetti, S., & Dupont, D. (2004). The performance of municipal water utilities: Evidence on the role of ownership. *Journal of Toxicology and Environmental Health*, *67*(20-22), 1861-1878. doi: 10.1080/15287390490492340

Ribeiro, O. D. J. (2014). *Serviços ambientais: o surgimento de arranjos institucionais* (Doctoral Thesis, Faculdade de Economia, Administração e Contabilidade, Universidade de São Paulo). Retrieved from www.teses.usp.br.

Rijsberman, F. R. (2006). Water scarcity: Fact or fiction?. *Agricultural Water Management*, *80*, 5-22. doi: 10.1016/j.agwat.2005.07.001

Rinehold, A., Corrales, L., Medlin, E., & Gelting, R. J. (2011). Water Safety Plan demonstration projects in Latin America and the Caribbean: Lessons from the field. *Water Supply*, *11*(3), 297-308. doi: 10.2166/ws.2011.050

Roshan, A., & Kumar, M. (2020). Water end-use estimation can support the urban water crisis management: A critical review. *Journal of Environmental Management*, *268*. doi: 10.1016/j.jenvman.2020.110663

Rule, S., Parker, S., Majikijela, Y., & Lunga, W. (2021). Neighbourhood responses to drought in the Western Cape. *GeoJournal*, *86*, 2267–2278. doi: 10.1007/s10708-020-10185-5

Russell, S., & Fielding, K. (2010). Water demand management research: A psychological perspective. *Water Resources Research*, *46*(5). doi: 10.1029/2009WR008408.

Sabesp – Companhia de Saneamento Básico de São Paulo (2020). Sustainability Report 2019. São Paulo: Sabesp. Retrieved from: https://tinyurl.com/bdzmtz9v.

Sabesp – Companhia de Saneamento Básico de São Paulo (2021). Sustainability Report 2020. São Paulo: Sabesp. Retrieved from: https://tinyurl.com/ms3fx7vs.

Sáez-Fernández, F. J., González-Gómez, F., & Picazo-Tadeo, A. J. (2011). Opportunity Costs of Ensuring Sustainability in Urban Water Services. *International Journal of Water Resources Development, 27*(4), 693-708. doi: 10.1080/07900627.2010.548316

Sampaio, P. R. P., & Sampaio, R. S. R. (2020). The challenges of regulating water and sanitation tariffs under a three-level shared-authority federalism model: The case of Brazil. *Utilities Policy*, *64*. doi: 10.1016/j.jup.2020.101049

Saneago – Saneamento de Goiás (2021). *Relatório Anual de Sustentabilidade 2020*. Goiânia, GO: Saneago. Retrieved from: https://tinyurl.com/2ax5w6hc.

Santos, J. R. et al. (2019). Water used to be infinite: A Brazilian tale of climate change. *Kybernetes, 48*(1), 143-162. doi: 10.1108/K-11-2017-0438

Santos, M. A, Fávero, L. P. L., & Distádio, L. F. (2016). Adoption of the International Financial Reporting Standards (IFRS) on companies' financing structure in emerging economies. *Finance Research Letters*, *16*, 179-189. doi: 10.1016/j.frl.2015.11.002

Saurí, D. (2020). The decline of water consumption in Spanish cities: structural and contingent factors. *International Journal of Water Resources Development*, *36*(6), 909-925. doi: 10.1080/07900627.2019.1634999

Sebri, M. (2014). A meta-analysis of residential water demand studies. *Environment, Development and Sustainability*, 16, 499-520. doi: 10.1007/s10668-013-9490-9

Seroa da Motta, R. S., & Moreira, A. (2006). Efficiency and regulation in the sanitation sector in Brazil. *Utilities Policy, 14*(3), 185-195. doi: 10.1016/j.jup.2006.03.002

Shahangian, S. A., Tabesh, M., Yazdanpanah, M., Zobeidi, T., & Raoof, M. A. (2022). Promoting the adoption of residential water conservation behaviors as a preventive policy to sustainable urban water management. *Journal of Environmental Management, 313*, 115005. doi: 10.1016/j.jenvman.2022.115005

Sikder, M., Wang, C., Yao, X., Huai, X., Wu, L., Kwameyeboah … Dou, X. (2022). The integrated impact of GDP growth, industrialization, energy use, and urbanization on CO_2 emissions in developing countries: Evidence from the panel ARDL approach. *Science of The Total Environment*, *837*. doi: 10.1016/j.scitotenv.2022.155795

Slovic, P., Fischhoff, B., & Lichtenstein, S. (1977). Behavioral decision theory. *Annual Review of Psychology*, *28*, 1-39.

SNIS – Sistema Nacional de Informações Sobre Saneamento (2022). *Diagnóstico dos Serviços de Água e Esgoto 2021: Technical Report*. Brasília, DF: Secretaria Nacional de Saneamento, Ministério do Desenvolvimento Regional. Retrieved from: http://antigo.snis.gov.br/diagnostico-anual-agua-e-esgotos.

Sobhani, F. A., Amran, A. & Zainuddin, Y. (2012). Sustainability disclosure in annual reports and websites: a study of the banking industry in Bangladesh. *Journal of Cleaner Production*, *23*, 75-85. doi:10.1016/j.jclepro.2011.09.023

Sousa, C. O. M., & Fouto, N. M. M. D. (2019). Economic incentives for water consumption reduction: case study of the city of São Paulo, Brazil. *Water Policy*, *21*, 1266-1278. doi: 10.2166/wp.2019.022

Sousa, C. O. M., & Fouto, N. M. M. D. (2023). A systematic review on household water consumption behaviour in times of water availability uncertainties. Efficient 2023 – IWA Conference on Efficient Urban Water Management. Retreved from: https://efficient.webs.upv.es/proceedings/

Sousa, C. O. M., Teixeira, L. V., & Fouto, N. M. M. D. (2022). Midterm impacts of a water drought experience: Evaluation of consumption changes in São Paulo, Brazil. *Water Policy*, *24*(1), 179-191. doi: 10.2166/wp.2021.120

Srdjevic, B., Srdjevic, Z. & Lakicevic, M. (2018). Validating the importance of criteria for assessing climate change scenarios. *Journal of Water and Climate Change*, *9*(3), 570-583. doi: 10.2166/wcc.2018.157

Stavins, R. N. (2005). *Do consumers react to the shape of supply? Water demand under heterogeneous price structures*. (KSG Faculty Research Working Paper Series RWP05-039, June 2005). Retrieved from: https://tinyurl.com/yhjhrnpx.

Stone, J. M., & Johnson, P. S. (2022). Conserving for the common good: Preferences for water conservation policies during a severe drought in Northern California. *Water Resources and Economics*, *37*, 100191. doi: 10.1016/j.wre.2021.100191

String. G., & Lantagne, D. (2016). A systematic review of outcomes and lessons learned from general, rural, and country-specific Water Safety Plan implementations. *Water Supply*, *16*(6), 1580-1594. doi: 10.2166/ws.2016.073

Tarne, P., Travezo, M., Finkbeiner, M. (2017). Review of Life Cycle Sustainability Assessment and Potential for Its Adoption at an Automotive Company. *Sustainability*, *9*(670). doi:10.3390/su9040670

Tiedmann, H. R., Spearing, L. A., Castellanos, S., Stephens, K. K, Sela, L., & Faust, K. M. (2023). Tracking the post-disaster evolution of water infrastructure resilience: A study of the 2021 Texas winter storm. *Sustainable Cities and Society*, *91*. doi: 10.1016/j.scs.2023.104417

Timmins, C. (2002). Demand-side technology standards under inefficient pricing regimes: Are they effective water conservation tools in the long run?. *Economics of Water Resource Management*, *26*, 123-146.

Tourino, M., Santos, P. R., Pinto, F. T., & Camanho, A. S. (2022). Performance assessment of water services in Brazilian municipalities: An integrated view of efficiency and access. *Socio-Economic Planning Sciences*, *79*. doi: 10.1016/j.seps.2021.101139

Tranfield, D., Denyer, D., & Smart, P. (2003). Towards a methodology for developing evidence-informed management knowledge by means of systematic review. *British Journal of Management*, *14*, 207-222: doi: 10.1111/1467-8551.00375

Tregidga, H., & Milne, M. J. (2006). From sustainable management to sustainable development: A longitudinal analysis of a leading New Zealand environmental reporter. *Business Strategy and the Environment*, *15*: 219-241. doi: 10.1002/bse.534

Truant, E., Corazza, L., & Scagnelli, S. M. (2017). Sustainability and risk disclosure: An exploratory study on sustainability reports. *Sustainability, 9*(636). doi: 10.3390/su9040636

Trumbo, C. W., & O'Keefe, G. (2005). Intention to conserve water: Environmental Values, reasoned action, and information effects across time. *Society and Natural Resources*, *18*(6), 573-585. doi: 10.1080/08941920590948002

Tsuda, M., Nishida, S., & Irie, M. (2014). Quantification of the adverse effects of drought caused by water supply restrictions considering the changes in household water consumption characteristics. *Water Supply*, *14*(5), 743-750. doi: 10.2166/ws.2014.030

Vallès-Casas, M., March, H., & Saurí, D. (2017). Examining the reduction in potable water consumption by households in Catalonia (Spain), Structural and contingent factors. *Applied Geography*, *87*, 234-244. doi: 10.1016/j.apgeog.2017.07.015

Van den Berg, C. (2015). Drivers of non-revenue water: A cross-national analysis. *Utilities Policy*, *36*, 71-78. doi: 10.1016/j.jup.2015.07.005

Van Vilet, M. T. H, Florke, M., & Wada, Y. (2017). Quality matters for water scarcity. *Nature Geoscience*, *10*, 800-802. doi: 10.1038/ngeo3047

Vilanova, M. R. N., Magalhães Filho, P., & Balestieri, J. A. P. (2015). Performance measurement and indicators for water supply management: Review and international cases. *Renewable and Sustainable Energy Reviews*, *43*, 1-12. doi: 10.1016/j.rser.2014.11.0

Villar-Navascués, R. A., & Fragkou, M. C. (2021). Managing water scarcity futures: Identifying factors influencing water quality, risk perception and daily practices in urban environments after the introduction of desalination. *Water*, *13*(19), 2738. doi: 10.3390/w13192738

Villar-Navascués, R. A., & Pérez-Morales, A. (2018). Factors Affecting Domestic Water Consumption on the Spanish Mediterranean Coastline. *Professional Geographer*, *70*(3), 513-525. doi: 10.1080/00330124.2017.1416302

Villegas, A., Molinos-Senante, M., & Maziotis, A. (2019). Impact of environmental variables on the efficiency of water companies in England and Wales: A double-bootstrap approach. *Environmental Science and Pollution Research*, *26*: 31014-31025. doi: 10.1007/s11356-019-06238-z

Wait, I. W., & Petrie, W. A. (2017). Comparison of water pricing for publicly and privately owned water utilities in the United States. *Water International*, *42*(8), 967-980. doi: 10.1080/02508060.2017.1406782

Wang Y. H., Chang M. C., & Liou J. R. (2019). Effects of water-saving education in Taiwan on public water knowledge, attitude, and behavior intention change. *Water Policy*, *21*, 964-979. doi: 10.2166/wp.2019.173

Wang, C. H., & Dong, H. (2017). Responding to the Drought: A spatial statistical approach to investigating residential water consumption in Fresno, California. *Sustainability*, *9*(240). doi: 10.3390/su9020240

Wang, W. Z., Liu, L. C., Liao, H., & Wei, Y. M. (2021). Impacts of urbanization on carbon emissions: An empirical analysis from OECD countries. *Energy Policy*, *151*, 112171. doi: 10.1016/j.enpol.2021.112171

White, M., Matthews, J. H., Lexén, K., Widforss, S., & Rodriguez, D. J. (2017). Water and climate change policy: A brief history for future progress. *Annales des Mines – Responsabilité et environment*, *86*(2), 56-61. doi: 10.3917/re1.086.0056

Wolters, E. A. (2014). Attitude–behavior consistency in household water consumption. *The Social Science Journal*, *51*(3), 455-463. doi: 10.1016/j.soscij.2013.10.003

Yuan, X. C., Wei, Y. M., Pan, S. Y., & Jil, J. L. (2014). Urban Household Water Demand in Beijing by 2020: An Agent-Based Model. *Water Resources Management*, 28, 2967-2980. doi: 10.1007/s11269-014-0649-4

Zhang, X., González Rivas, M., Grant, M., Warner, M. E. (2022). Water pricing and affordability in the US: Public vs. private ownership. *Water Policy*, *24*(3), 500. doi: 10.2166/wp.2022.283

APPENDIX A - TREATED SNIS DATABASES

OWNERSHIP IN TIMES OF WATER SCARCITY

Available on Excel format in the link:

https://docs.google.com/spreadsheets/d/1idG08j2JSJghKoPEPdTxTRLART3WaRol/edit?usp=drive_link&ouid=115464786316934266277&rtpof=true&sd=true

DRIVERS OF NRW

Available on Excel format in the link:

https://docs.google.com/spreadsheets/d/1Amza6UGXkFdefoCNUwiFOPXT7XTtbVNN/edit?usp=drive_link&ouid=115464786316934266277&rtpof=true&sd=true

APPENDIX B – RESEARCH PROTOCOL

RESEARCH:	**Residential Water Consumption Behavior**	
AUTHORS	Cláudia Orsini Machado de Sousa Nuno Manoel Martins Dias Fouto	
KEY-WORDS	Behavior, water consumption, water scarcity, household	
CONTEXT	Drinking water scarcity is an issue becoming more frequent throughout the world. It is crucial to understand factors that induce population to reduce water consumption and use it more rationally.	
RESEARCH QUESTION	Which factors influence household water consumption, in the context of water scarcity?	
SEARCH CRITERIA	**Databases**	Scopus and Web of Science
	Period	2010- 2022
	Publication type	Research paper, Review paper – only documents written in English were selected and peer reviewed.
	String	"water consumption" and ("behavior" or "behaviour") and ("drought" or “scarcity” or “water stress” or “water crisis”) and (“residential” or “household” or “households” or “residence” or “residences” or “urban”)
	Where	Title, Abstract, keywords.
	Selection process	1) Article searching on the databases 2) Elimination of duplicated articles 3) Revising titles and abstracts from the selected articles
	Inclusion criteria	IC1: The article reports an evaluation of residential water consumption in a water scarcity context IC2: The article analyzes factors that shape water consumption behavior
	Exclusion criteria	EC1: The article does not focus on residential water consumption behavior EC2: The article does not analyze a specific case of water scarcity EC3: The article focuses on rural water consumption rather than residential water consumption