Since January 2020 Elsevier has created a COVID-19 resource centre with free information in English and Mandarin on the novel coronavirus COVID-19. The COVID-19 resource centre is hosted on Elsevier Connect, the company's public news and information website.

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COVID-19 and organisational resilience in Brazil's water sector

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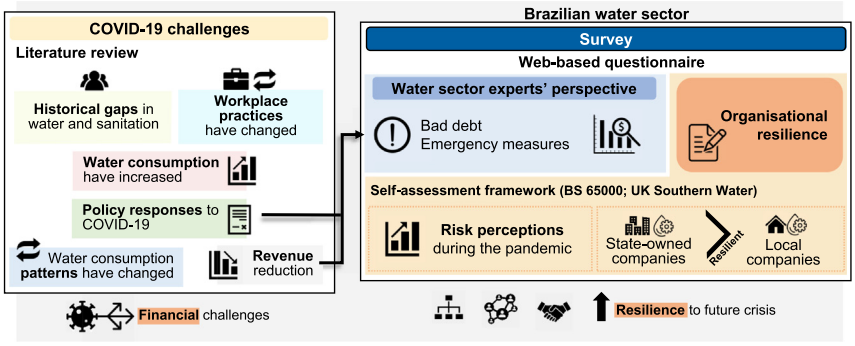
HIGHLIGHTS

- COVID-19 globally exacerbated pre-existing challenges in water sector.
- COVID-19 has been a threat multiplier for water sector financial issues.
- Brazilian water companies were assessed in relation to their resilience maturity.
- State-owned companies had higher level of resilience maturity than local companies.
- Water companies can learn from their response to COVID-19 to strengthen resilience.

GRAPHICAL ABSTRACT



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ABSTRACT

The COVID-19 pandemic required a wide range of adaptations to the way that water sector operated globally. This paper looks into the impact of the COVID-19 pandemic on Brazilian water sector and evaluates the water sector's organisational resilience from the lens of water professionals. This study uses British Standard (BS 65000:2014)'s Resilience Maturity Scale method to evaluate organisational resilience in water sector under two defined scenarios of before and during the pandemic. For this purpose, the self-assessment framework developed by Southern Water in the United Kingdom (based on BS 65000:2014), comprising of the core resilience elements of Direction, Awareness, Alignment, Learning, Strengthening, and Assurance, are used for evaluations. A qualitative-quantitative surveying method is used for data collection. A total of 14 responses to the whole questionnaire were received from May 2021 to August 2021, each representing one water company in Brazil (four local companies and ten state-owned ones). The analyses identified COVID-19 as a threat multiplier particularly to already existing financial challenges due to the pre-existing threats in water sector. Bad debt and the COVID-19 emergency measures are recognised as the main challenges by 21 % and 14 % of the survey respondents. The state-owned and local companies scored an almost similar maturity level 3, 35 % and 34 % respectively, while the local companies scored much lower at maturity level 4 i.e., 26 % as opposed to 47 % in state-owned sector. This indicates that COVID-19 has a greater impact on local companies and the needs to increase preparedness. This study replicates an international experience to raise awareness on water sector's resiliency in Brazil and how it can be improved to withstand future external shocks. It sheds light on how and what existing challenges can be exacerbated facing a global shock and proposes opportunities for improvement of resilience maturity in water sector in Brazil.

1. Introduction

The World Health Organisation (WHO) recognised the coronavirus disease (COVID-19) outbreak as a pandemic on 11 March 2020 and since then, the world has experienced rapidly growing threat to global health security

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(Acter et al., 2020; Chakraborty and Maity, 2020; Zumla and Niederman, 2020). The COVID-19 is the infectious disease caused by the severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) virus, a novel and highly transmissible coronavirus (Ahmed et al., 2021; Hu et al., 2021). In order to help prevent the virus transmission, especially in high-density urban areas, several countries have implemented a series of precautionary measures, including quarantine, social distancing, lockdowns and behavioural guidelines such as frequent handwashing. Recent studies showed the effectiveness of such measures in reducing the rate of infection (Delen et al., 2020; Saez et al., 2020; Sypsa et al., 2021; Tobías, 2020). Handwashing with soap is one of the simplest and most effective ways to prevent infections and further evidence suggests that improvements in hand hygiene may reduce spread of respiratory viruses and other infectious diseases (Aiello et al., 2008; Haque, 2020; Hirose et al., 2021; Islam et al., 2022; Warren-Gash et al., 2013). As water, sanitation and hygiene (WASH) facilities are important to protect public health especially during infectious disease outbreaks, the water sector is considered an essential due to its vital role supplying drinking water and collecting and treating sewage (WHO; UNICEF, 2020).

Despite water's importance, more than 2 billion people across the globe still lack access to safely managed drinking water and over half lack access to safely managed sanitation (United Nations, 2020b). Most of these historical access gaps still take place in low- and middle-income countries (LMICs), as defined by the World Bank (The World Bank, 2021), making them particularly vulnerable to disruptive events such as COVID-19. The COVID-19 crisis represents a severe threat to LMICs, since they face other simultaneous pressures related to rapid urbanisation and population growth (e.g., increasing informal settlements, with limited access to health and WASH services), poverty, inequality, unemployment and underemployment, other infectious diseases (e.g., malaria, dengue fever), limited financial resources, and high public debt levels (Ahmed et al., 2020; Barbier and Burgess, 2020; Khatri et al., 2008). Under this scenario, the measures to fight COVID-19 are difficult to implement and the emergency response must tackle new and existing inequalities (Parikh et al., 2020; Patel et al., 2020).

The COVID-19 crisis has been associated with social and economic impacts (e.g., financial losses, mental health issues), often unevenly distributed across different countries and social groups (Osterrieder et al., 2021). In addition, COVID-19 and the related emergency measures have affected the environment and increased pressure on water supply and sanitation sector (Butler et al., 2020; Parikh and Rawtani, 2022). Recent studies have identified the presence of SARS-CoV-2 in sewage and receiving water bodies (Baldovin et al., 2021; Jakariya et al., 2021; Zamhuri et al., 2022). Other studies have reported an increased water consumption due to the changes in hygiene and cleaning habits (Abu-Bakar et al., 2021; Sayeed et al., 2021). Also, the waste generation has increased globally as a result of the pandemic, and improper disposal represents a major threat to aquatic environments (Ali and Parvin, 2022). These new challenges may overburden the water sector, which is already under stress in LMICs due to the pre-COVID threats (Butler et al., 2020).

Brazil is one of the LMICs where the COVID-19 pandemic has amplified the water sector pre-existing trends. At end of 2021, Brazil had accumulated more than 22 million COVID-19 cases and 619,056 deaths and was the country with the world's third and second highest numbers of confirmed COVID-19 cases and reported deaths, respectively (Johns Hopkins University, 2021). When it comes to water and sanitation services, 84 % of the Brazilian population had access to the water supply system and 55 % had access to the sewerage system in 2020 (Brazil, 2021a). The population most impacted by the lack of these services live in low-income areas, such as indigenous villages, urban peripheries and informal settlements, which are more vulnerable and susceptible to infectious diseases (SIWI; UNICEF Brazil; The World Bank, 2020).

Drawing on the above, it is clear that water sector plays a crucial role in Brazil's response to the pandemic. Nevertheless, the existing pressures on water supply and sanitation services along with the lack of effective resilience strategies prior to the pandemic were exacerbated by COVID-19 leading to insufficient/ineffective response by the sector. The implications of such exacerbations clearly demonstrate a wide range of short-term and long-term impacts that the sector need to tackle and cope with in coming years. In order to address the need of the water sector to have the necessary capacity to respond to disruptive events and chronic conditions, the concept of resilience could be applied and understood as a business continuity and risk management model (Lawson et al., 2020). The Water Services Regulation Authority – (OFWAT, 2015), defined resilience as "*the ability to cope with, and recover from, disruption and anticipate trends and variability in order to maintain service for people and protect the natural environment now and in the future*". As a business, water companies need to incorporate resilience to respond and recovery from adverse conditions, linking corporate (business operations issues), operational (performance ones) and financial elements in strategic planning process, while prioritizing customers' expectations (OFWAT, 2017). This means considering all potential threats to different departments to adopt a well-rounded approach, called "resilience in the round" in OFWAT's 2019 price review (PR19).

The COVID-19 crisis reinforced the importance of resilience in water systems and how we can learn lessons from this crisis for further future-proofing of water systems. Resilience has been widely discussed in global water sector from regulatory/government level to local level (Butler et al., 2017; Johannessen and Wamsler, 2017). Nevertheless, this is an emerging discussion in the Brazilian water sector, whose primary concern is still achieving universal access to safely managed water and sanitation services (Diep et al., 2020). Many authors agree that an exit strategy from a crisis will be a strategy that embraces a resilience approach and develops its capacities to bounce back and learn lessons for the future (Lawson et al., 2020; Makropoulos et al., 2018; OFWAT, 2017). Therefore, the challenges to building resilience in Brazilian water systems are important to discuss, especially in the face of the COVID-19 pandemic.

This study aims to analyse the performance of the Brazilian water sector in response to the COVID-19 pandemic and assess the major challenges faced by water companies. The resilience self-assessment framework developed by Southern Water in the United Kingdom (UK) (SWS, 2018) was used to assess the water sector performance against six resilience elements: Direction, Awareness, Alignment, Learning, Strengthening, and Assurance. The companies' performance from the water professionals' perspective was scored, via a structured questionnaire, considering two scenarios (before and during the pandemic). Recently, similar studies have been developed to assess the water sector responses and the impacts on projects, practices and workers (Antwi et al., 2021; Capodeferro and Smiderle, 2020; Goldin et al., 2022; Lawson et al., 2020; Renukappa et al., 2021; Spearing et al., 2021). To the best of our knowledge, there are no prior studies measuring the water sector organisational resilience in Brazil.

2. The challenges of urban water sector in Brazil

2.1. The institutional framework of water sector in Brazil and its challenges

The Brazilian government began tackling Water Supply and Sanitation (WSS) services issues through collective solutions only in 1940, when the population was already around 40 million inhabitants and 70 % of them did not have a safely managed drinking water service (Pagnoccheschi, 2016). Since then, water sector governance has been frequently a reactive response to lack of access to WASH services, and hence Brazil has a complex governance which involve several government agencies and service providers at different government levels (Fig. 1). Recently, an update to the water sector legal framework (Federal Law n. 14,026/2020) was approved by the Brazilian federal government, known as the "New Sanitation Framework" (Brazil, 2020). The purpose of this update was to improve cross-sectoral coordination for infrastructure development (Cunha Libanio, 2020). The law will have significant impact on the water sector regulation and the new WSS concessions (de Sousa, 2020).

In Brazil, WSS are considered local public services and, as such, municipal governments are the authority responsible for their provision. Under the framework from Fig. 1, the municipality may provide the services at local level by municipal secretariats or autarchies, or delegate the operation

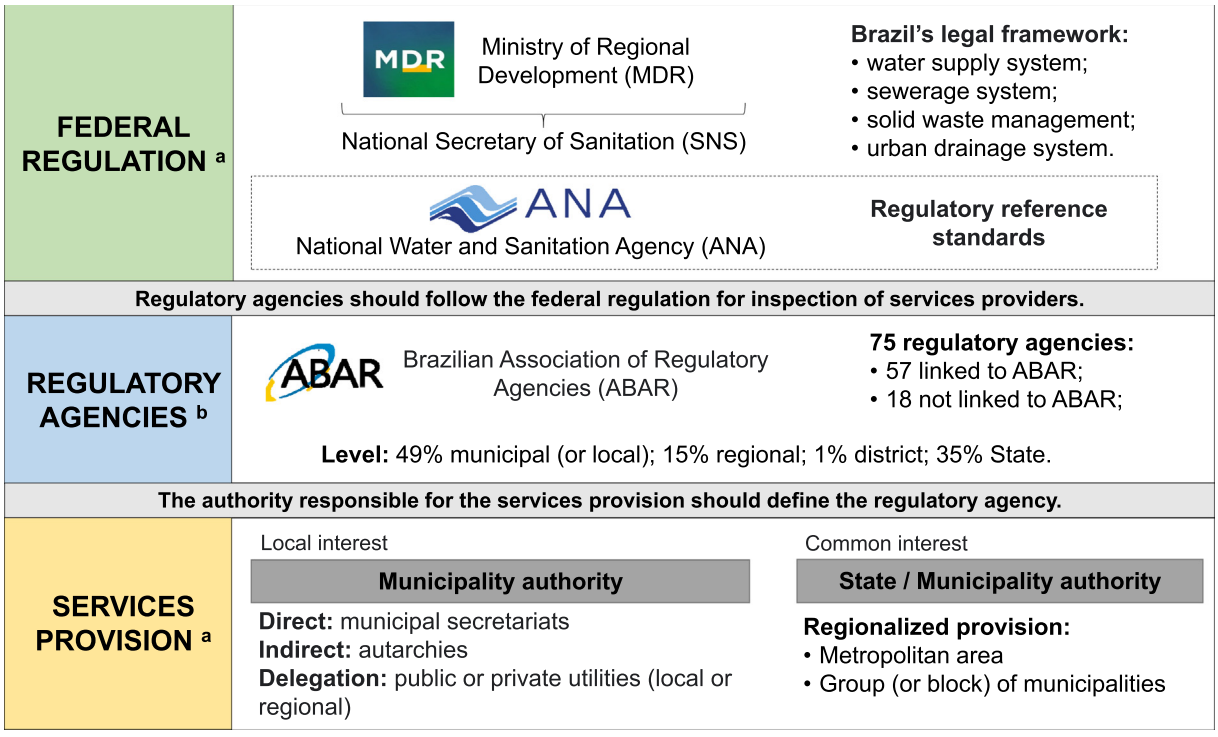

Fig. 1. Brazil's water sector institutional framework.
[a]Brazil (2020); [b]ABAR (2020a).

to public or private utilities, that are generally regional. In cases where the services' provision is of common interest to more than one municipality, municipal governments share the authority with the state government. Regarding regulation, the authority may delegate the responsibility to a regulatory agency, and it can be exercised at either municipal, regional or state levels (Barbosa and Brusca, 2015; Smiderle et al., 2020). It is noteworthy that almost 60 % of the Brazilian municipalities are regulated by regulatory agencies (ABAR, 2020a).

Despite the relevance given to the municipal authority under the Brazilian water sector framework, the provision and regulation of the WSS services have been historically treated mainly at the state level (Sampaio and Sampaio, 2020). In 2020, the National Sanitation Information System (SNIS) reported the existence of 1,354 service providers: 28 regional companies (26 state-owned), 8 micro-regional companies, and 1,318 local companies (Brazil, 2021a). Regional utilities serve 81 % of the total Brazilian population and 91 % of the urban population with water supply (Brazil, 2021a). Regarding sewage, they cover 47 % of the total Brazilian population and 55 % of the urban population with sewerage system. About 50 % of the sewage generated is treated (Brazil, 2021a). Most state-owned companies (approximately 24) are mixed capital companies with the state government as the majority shareholder (Vitoria et al., 2020). Private companies are responsible for only 8 % of the sector's market share (Brazil, 2021a).

The complex and multi-level water governance in Brazil leads to the existence of different stakeholders that make the decision-making processes and the adoption of integrated and innovative approaches more challenging (Organisation for Economic Co-operation and Development – OECD, 2015). According to Sampaio and Sampaio (2020), this shared-authority system ended up often leading to power disputes and legal uncertainty. Also, such complexity has affected the efficiency of the sector's policies and resulted in conflicting roles regarding services provision and infrastructure management (Diep et al., 2020). Hence, when a crisis such as COVID-19 pandemic occurs, complex systems, such as Brazil's water sector, may take longer to respond effectively and efficiently if they are not well articulated (Ramos and Hynes, 2020). As a result of this, key resilience principles, such as redundancy, interconnectivity and learning, are challenging to operationalise considering different design or planning practices of non-articulated governances (Rodina, 2019).

2.2. COVID-19-related challenges in water sector: a brief review

A key facet of resilience-informed water management is the identification, characterisation, and categorisation of potential threats. Hence, considering the context prior to COVID-19, a narrative review of the literature was conducted on the water sector drivers or threats from a series of searches using Web of Science, Google Scholar and Scopus databases, as well as policy documents and reports from governments, agencies and international organisations. This investigation diagnoses the underlying challenges of water sector prior to COVID-19 and their likely coincidence with emerging COVID-19-induced pressures leading to exacerbation of service delivery in Brazil. One of the key factors in projection of resilience is to understand the interlinkages in water sector to tackle the issues around cascading failures. According to Rehak et al. (2018), cascading impacts "are impacts caused by disruptions or failures in an element/sub-sector/sector of the critical infrastructure that continue to spread across the critical infrastructure – and cause a failure of dependent elements/sub-sectors/sectors – which result(s) in the escalation of further impacts".

The result of the above literature survey can be conceptually demonstrated as the four zones defined in Fig. 2 to categorise the pre- and post-COVID-19 threats. This categorisation supports better identification of existing and emerging key threats and their linkages in water sector by service providers, policymakers and regulators. Moreover, this partitioning approach can facilitate the mapping of cascaded impacts for more targeted diagnostic analysis and aid prioritisation of resilience interventions.

Shocks are disruptive and acute events that may affect the companies' ability to provide WSS services in the short term (e.g., abrupt changes in water consumption, droughts events). Some shocks may have long-term impacts due to prolonged disturbances on companies, such as water licensing changes. Conversely, stresses are chronic and slow-onset events that can

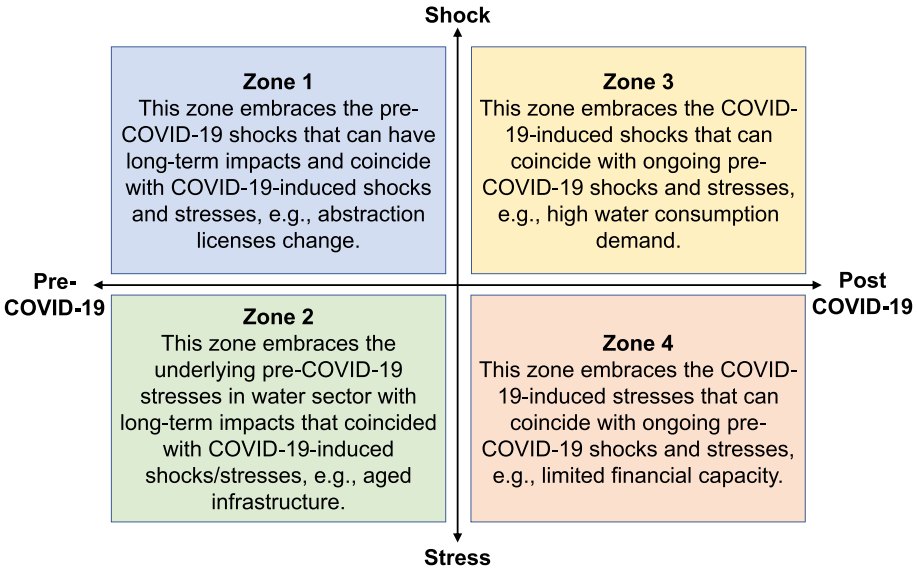

Fig. 2. Key Pre/Post COVID-19 threats in/to water sector in Brazil.

impair the operation and efficiency of water sector and increase their vulnerabilities (e.g., population growth, climate change) (ARUP and Anglian Water, 2018; Sturgess, 2015). In Fig. 2, Zone 1 and Zone 2 indicate the pre-COVID-19 potential shocks and stresses, respectively. Zones 3 and 4 represent new COVID-19-induced challenges (e.g., social distancing) and pre-COVID-19 challenges that the pandemic can exacerbate (e.g., behavioural changes). The coincidence of the COVID-19 with ongoing pressures may lead to further interruption of the services, along with a prolonged recovery process.

Table 1 outlines some key findings of the above investigation as common problems of water sector companies in Brazil before the pandemic (pre-COVID-19 potential shocks and stresses from Zones 1 and 2, respectively). The pre-COVID-19 threats that may be induced or exacerbated by the COVID-19 pandemic (i.e., Zones 3 and 4) were separated into potential and actual. They refer, respectively, to events that may happen and events that already happened due to the interaction with the pandemic and the ongoing threats. This characterization as 'potential' or 'actual' was based on the reports found in the literature review and published during the COVID-19 pandemic.

Fig. 3 summarizes the main challenges expected for the Brazilian water sector due to the COVID-19 pandemic, based on the literature review (Table 1), which are discussed in Sections 2.2.1 to 2.2.6.

2.2.1. Brazil's historical gaps in WSS services

The population in Brazil reached 213 million inhabitants in 2021 (IBGE, 2020a). As many LMICs, Brazil has experienced a rapid population growth and urbanisation over the past decades. One of the major effects of this rapid growth is the poorly planned urban development, which may affect the ability of local governments to provide infrastructure and basic public services for all people (UN-Habitat, 2016). Due to the increasing demands and the housing needs without proper planning, socioeconomic factors such as poverty, marginalisation and informality are an ever-present reality in many of the countries with high population growth rates (UNDESA/PD, 2019). As a result, informal settlements and slums emerge and grow, especially in the peri-urban areas of large cities such as São Paulo and Rio de Janeiro (Adeyeye et al., 2020). These settlements often have limited or inadequate access to improved water sources and sanitation facilities, as well as overcrowding and lack of quality/durability of housing (UN-Habitat, 2003). In 2019, there were about 5 million households in informal urban settlements in Brazil (IBGE, 2020b).

Water policy continue to be a key player in response to COVID-19, particularly because the most vulnerable areas to the spread of contagious diseases have lower access to WASH and health services (SIWI; UNICEF Brazil; The World Bank, 2020). According to data from the SNIS, 16 % of Brazilian households lack access to drinking water and 45 % do not have access to the sewerage system in 2020 (Brazil, 2021a). This historical gap also holds an inter-regional dimension due to an uneven distribution of water supply network and sewage collection. The North region had the lowest water supply coverage in 2020 (59 %), whereas the Southeast region reached 91 %. Regarding sewage, the North and Southeast regions had coverages of 13 % and 80 % in the same year, respectively (Brazil, 2021a).

Brazil's historical gaps in WSS services can be further widened in crisis situation such as the COVID-19 pandemic which requires swift and effective co-ordination, collaboration and action during and post pandemic. COVID-19 has created social challenges for the nation particularly in deprived communities with lower access to WASH (United Nations, 2020a). According to 2019 data from the Trata Brasil (ITB), people without access to WSS services had an average monthly income of approximately R$ 515 ($ 100, USD dollar exchange rate of June 14, 2022), almost six times lower than the monthly income of people with access to these services (ITB, 2019). Since COVID-19 trigged economic and employment shocks, an increase in poverty, social vulnerability and inequality is expected if Brazilian policy responses are not effective and well-coordinated (The World Bank, 2020). In this regard, different government levels have created initiatives to limit the socio-economic impacts of the COVID-19 pandemic, such as emergency financial assistance and the suspension of water service shut-off to protect the poor and the most vulnerable people.

2.2.2. Policy responses to COVID-19

Water sector had to deal with policy responses attempted to limit the socio-economic impact of the COVID-19 pandemic. Some commonly measures adopted voluntarily or by state government order in Brazil, since the first confirmed case on 26 February 2020, were: (i) limits on the number of workers in the workspace and rules on social distancing; (ii) partial or total suspension of water billing for low-income users; (iii) suspension of water service shut-off due to non-payment; (iv) flexible payment plans and alternative payment methods; (v) postponement of the application of tariff adjustments; and (vi) prohibition on charging late fees or other penalties (ABAR, 2020b; Smiderle et al., 2020). While these measures have been essential to support the most vulnerable people, they could lead to financial and operational impacts and high risks to water sector performance when taken without proper planning (Butler et al., 2020).

The water-related measures were implemented to some extent in most Brazilian states (e.g., Acre, Amazonas, Bahia, São Paulo, Rio de Janeiro). However, they were often not well articulated and there was no national strategy for the COVID-19 response (Victral and Heller, 2021). Such lack

Table 1
Known shocks and stresses to the water sector prior to COVID-19, considering the Brazilian context, and how they relate to the pandemic.

Zone 1 pre-COVID-19 potential shocks	Zone 3 induced or exacerbated by COVID-19		
	Potential	Actual	COVID-19-related references
Infrastructure failure (e.g., incidents, mechanical or supply chain failure)[a, b, c]	X	–	(Spearing et al., 2021)
Water quality standards change[c]	–	–	–
Power outages[a, d]	X	–	(Abu-Bakar et al., 2021)
Energy price changes[d]	X	–	(Norouzi et al., 2021)
Water supply contamination (e.g., oil and chemical spills)[d]	–	–	–
Abrupt changes in water consumption[d]	–	X	(Abu-Bakar et al., 2021; Kalbusch et al., 2020)
Abrupt changes in water quality or sewage composition[d]	X	–	(Muduli et al., 2021)
Abstraction licences change[d]	–	–	–
Water-related diseases (e.g., cholera)[e]	X	–	(Rimoldi et al., 2020)
Flooding and droughts events[b, f]	–	–	–
Cyber-attacks[b, d, g]	–	–	–

Zone 2 pre-COVID-19 stresses	Zone 4 induced or exacerbated by COVID-19		
	Potential	Actual	COVID-19-related references
Population growth and urbanisation[b, c, e, g, i, j, k, l]	–	–	–
Changes in lifestyle and consumption patterns[b, d, e, k, m]	–	X	(Abu-Bakar et al., 2021; Campos et al., 2021; Kalbusch et al., 2020)
Increasing income inequality[c, g]	–	X	(Angelov and Waldenström, 2021)
Increasing informal urban settlements[e, h, m]	–	–	–
Climate change (inc. drought and flooding events)[c, e, f, h, i, j, m, n]	–	–	–
Changes in land use patterns[e, i, l]	–	–	–
Source water quality deterioration[c, e, h, l]	–	–	–
Water scarcity[c, e, l, m]	–	X	(Keulertz et al., 2020; Staddon et al., 2020)
Lack of or insufficient infrastructure[i, j, m, n]	–	X	(Butler et al., 2020; Stoler et al., 2020)
Ageing and deterioration of existing infrastructure systems[a, b, d, i, m]	X	–	(Butler et al., 2020; Spearing et al., 2021)
Outdated or insufficient technology[f, m]	X	–	(Butler et al., 2020; Spearing et al., 2021)
Leakage[b, d]	–	–	–
Bad debt[b, d]	–	X	(Spearing et al., 2021)
Poor financial and operations management[i, n]	X	–	(OECD, 2020)
Limited financial capacity[i, o]	–	X	(Butler et al., 2020; Spearing et al., 2021)
Shortage of skilled labour or lack of technical capacity[d, i, m, o]	–	X	(Cotterill et al., 2020; Spearing et al., 2021)
Lack of ownership or engagement in decision-making processes[b, d, i, m]	X	–	(Butler et al., 2020; OECD, 2020)
Governance & privatization (e.g., changing regulation, ineffective governance, failure of policy to promote innovations)[d, m]	–	X	(Spearing et al., 2021)

Note: lines with "-" correspond to threats that are not likely to be induced/exacerbated by the pandemic according to the data collected in this literature review.
[a] Gheisi et al. (2016).
[b] Defra (2017).
[c] Makropoulos et al. (2018).
[d] ARUP and Anglian Water (2018).
[e] Gallopín (2012).
[f] Luh et al. (2017).
[g] Lawson et al. (2020).
[h] Rahmasary et al. (2019).
[i] Adeyeye et al. (2020).
[j] Mourad (2020).
[k] Kizhisseri et al. (2021).
[l] Zimmerman et al. (2008).
[m] Khatri et al. (2008).
[n] Schultz and Uhlenbrook (2008).
[o] Johannessen and Wamsler (2017).

of national coordination may increase risks to service continuity and affect the post-COVID-19 recovery (ABAR, 2020b). The measures to financially support water service providers were mainly focused on payment extensions and emergency funding, but information on the financial management of water companies during the pandemic demonstrates an even greater lack of coordination with state policies (Artigo 19, 2020).

2.2.3. Increased water consumption and changes in water consumption patterns

One of the primary challenges water sector faced at outset of COVID-19 and beginning of the community containment strategy was increasing water demand due to hygienic and sanitation purposes as well as changing water consumption patterns as a result of staying and working from home (Campos et al., 2021; Capodeferro and Smiderle, 2020). Working from home culture has led to the type of water usage changes since office/work consumption patterns have shifted to household consumption patterns. Despite this shift across different types of water demands, water consumption had a net increase due to handwashing and 'new' cleaning/hygienic habits to prevent and control the COVID-19 spread (Abu-Bakar et al., 2021; Campos et al., 2021; Sayeed et al., 2021). In Joinville, Southern Brazil, analysis of data from 26 days before and 26 after the community containment measures revealed that water consumption decreased by 53 %, 42 % and 30 % in the industrial, commercial and public categories, respectively, and increased by 11 % in household category (Kalbusch et al., 2020).

The other challenge potentially exacerbated by the COVID-19 pandemic is the increase in domestic wastewater production, as a consequence of increased water consumption (Quintuña and Marcelo, 2020). COVID-19 has also exacerbated the effects of water scarcity, as access to water supply is essential to enable handwashing and proper hygiene. Several studies from other countries have reported that the pandemic has increased pressure

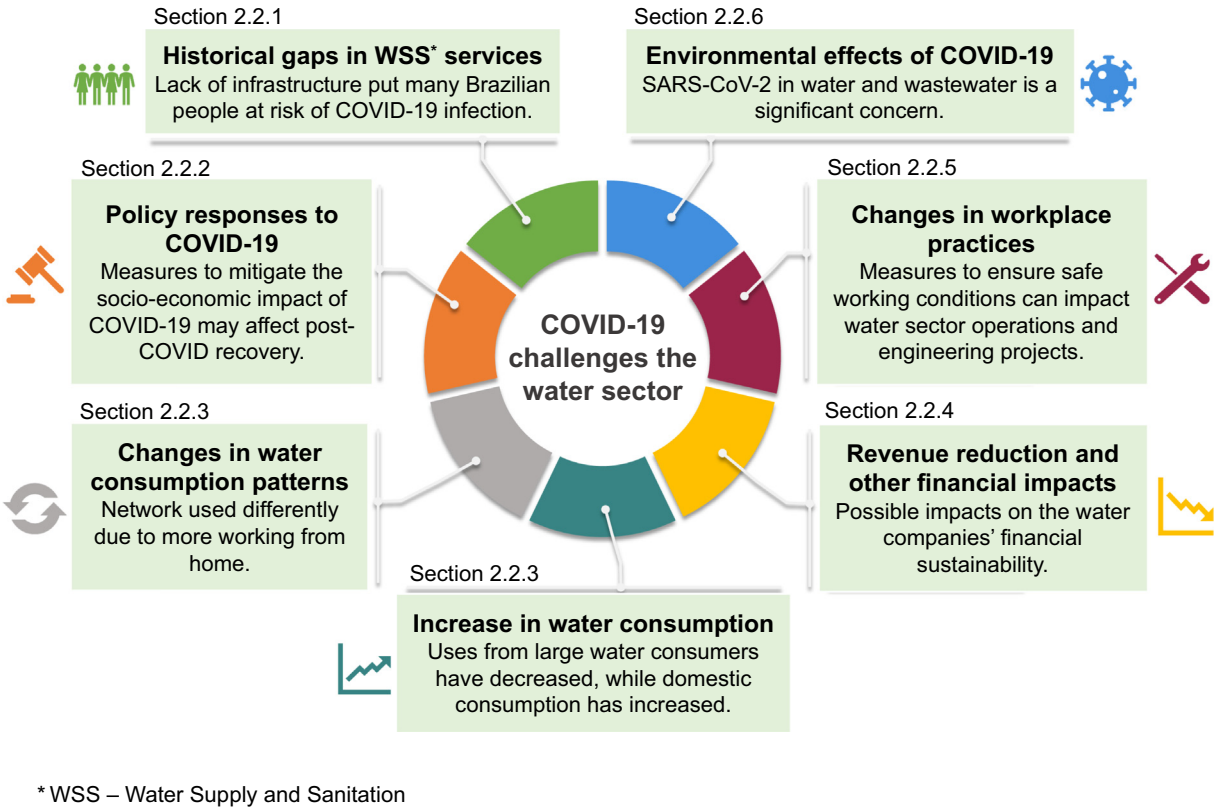

Fig. 3. Main challenges of the COVID-19 pandemic to the Brazilian water sector.
*WSS – Water Supply and Sanitation.

on already strained water supply systems (Boretti, 2020; Feizizadeh et al., 2021; Lawson et al., 2022). All the aforementioned issues may expose both water and wastewater sectors to pre-existing challenges such as ageing and insufficient infrastructure, outdated technology and poor maintenance and management (ARUP, 2016; Stepping, 2016).

2.2.4. Revenue reduction and other financial impacts

The economic crisis caused by the COVID-19 pandemic has impacted and will continue to affect the water sector's revenues and expenditures. The above-mentioned changes across different types of water demands (i.e., increase in household consumption and decrease in commercial/industrial consumption) have a negative impact on companies' revenue due to the water tariff structure (Barbosa and Brusca, 2015; Capodeferro and Smiderle, 2020). Larger water consumers (e.g., universities, shopping malls, industries) usually pay higher rates than small consumers, which may lead to a reduction in revenues during the COVID-19 pandemic. Behaviour changes and increased water consumption can also increase energy consumption in water and sewerage systems. In addition, COVID-induced energy price changes tend to lead to higher expenses with electricity.

Other challenges are the temporary suspension of water billing for low-income users and water service shut-off, as well as the increased level of bad debt. In April 2020, the level of bad debt was about 24 % in state-owned companies and 25 % in private companies (Hirata, 2020). SABESP - one of the largest water sector companies in Brazil - in its annual financial report in 2020 - has reported a 71 % decrease in net income, compared to 2019, and an allowance for doubtful accounts of R$ 444.8 million. Also, the exemption to low-income customers between the months of April and August/2020 cost about R$ 125.0 million (SABESP, 2021). Thus, water sector should expect an increase in total expenditure and decrease in revenues. These challenges may induce or exacerbate financial problems, especially for local companies that already had limited financial capacity before the pandemic.

2.2.5. Changes in workplace practices

The COVID-19 pandemic has forced organisations to adapt their workplace practices and operations (Renukappa et al., 2021; Spearing et al., 2021). New ways of working were developed to protect safety and health at work, including social distancing, remote working, handwashing, the use of face masks and alcohol-based products. The daily operation of the customer services such as call centres, maintenance services, or system improvements such as water meter installations were delayed, paused or stopped as a result of lockdown and social distancing. Staff shortages are also expected during the pandemic, as a consequence of reduced work teams, excused absences, and early retirements. These shortages were observed in studies conducted in other countries (Cotterill et al., 2020; Spearing et al., 2021). As operators play a critical role in Brazilian WSS utilities operations, lack of staff may affect maintenance strategies and system performance. One of the key challenges that in short- and long-term water systems will face is the cost of delayed services and the challenges around prioritisation of those services. It may lead to long-term reputational impacts around customer services. In addition, these service interruptions or delays will have short-term and long-term knock-on effects on other interdependent systems. As a result, more challenging issues may arise, such as the companies' ability to comply with the obligations of their concession contract regarding expanding services coverage.

2.2.6. Environmental effects of COVID-19

The COVID-19 pandemic and its related measures have caused adverse effects on the environment that may impact the water sector operations. Recent studies detected the presence of SARS-CoV-2 RNA in wastewaters and water bodies in Brazil (Prado et al., 2020, 2021) and other countries (Baldovin et al., 2021; Foladori et al., 2020; Jakariya et al., 2021; Lahrich et al., 2021; Rimoldi et al., 2020; Zamhuri et al., 2022), mostly those receiving non-treated or secondary-treated wastewaters. In Brazil, the sewerage system covers 55 % of the total population and 63 % of the urban

population (Brazil, 2021a). Approximately 50 % of the wastewater generated is treated before discharge to receiving water bodies (Brazil, 2021a). In addition, most of the Brazilian wastewater treatment plants do not remove pathogens by disinfection methods (von Sperling, 2016). Although the infectivity of SARS-CoV-2 in wastewaters and surface waters has not been proved, potential public health risks may arise considering the Brazil's historical gaps in WSS services.

During the COVID-19 pandemic, waste generation and composition has changed and several studies have reported a significant increase in medical waste, plastic pollution and use of disinfectants (Ali and Parvin, 2022; Penteado and de Castro, 2021). Further evidence from Brazil suggested a decrease in recyclable collection and a lack of proper treatment of medical waste (Urban and Nakada, 2021). Improper handling and disposal of wastes may result in soil, water and air pollution, causing adverse effects on human health (Ali and Parvin, 2022). Moreover, the detection of COVID-19-related pharmaceuticals, chlorinated disinfectant residues and harmful disinfection byproducts on aquatic environments has been an increasing concern worldwide (Bandala et al., 2021; Chu et al., 2021). All these emerging issues may expose water utilities to hazards and hazardous events, increasing the risks of water insecurity. Therefore, a pandemic risk assessment and management framework are essential to address the environmental, social and health implications of the above-mentioned challenges (Bogler et al., 2020; Girón-Navarro et al., 2021).

3. Materials and methods

3.1. Resilience assessment

The present study focuses on water sector's resilience in Brazil from organisational point of view. It analyses the performance of water sector in response to the COVID-19 pandemic and its challenges based on the water sector professionals' perspective. In this study, the framework developed by the UK Southern Water is used to assess the organisation's overall approach to resilience (SWS, 2018). The assessment framework adopted has been aligned to the principle and structure of British Standard (BS) 65000:2014 – Guidance on organisational resilience (BSI, 2014). BS 65000 defines organisational resilience as "*the ability of an organisation to anticipate, prepare for, respond and adapt to incremental change and sudden disruptions in order to survive and prosper*". The UK Southern Water approach uses the six elements of Direction, Awareness, Alignment, Learning, Strengthening, and Assurance, based on the BS 65000's core elements (SWS, 2018):

1. Be informed (Awareness): process and systems provide visibility of pressures and threats and current level of resilience;
2. Set direction (Direction): top-level managers identify pressures and threats and set resilience objectives;
3. Bring coherence (Alignment): resilience objectives shared, aligned, and managed across all operational disciplines;
4. Develop adaptive capacity (Learning): learn from internal and external experiences to identify resilience needs and opportunities and adapt to changing conditions;
5. Strengthen the organisation (Strengthening): implement solutions to enhance resilience and organisation's ability to deal with emerging risks and changing conditions;
6. Validate and review (Assurance): corporate view of resilience validated by audits, simulations, and stress tests.

To assess the performance of the sector against each element, this study used BS 65000 Resilience Maturity Scale method to evaluate the current level of resilience in water sector in response to COVID-19 pandemic. Five maturity levels of Maturity 0, Maturity 1, Maturity 2, Maturity 3 and Maturity 4 are defined each with a descriptive title as 'Immature', 'Aware', 'Developed', 'Competent' and 'Excellent', respectively (Table 2). The maturity scales demonstrate the overall approach to resilience planning in water sector in Brazil and the descriptive titles can reflect on the steps taken by an organisation to be more resilient to emerging challenges. For example, an 'Immature' organisation is one that has not taken any steps to apply and implement any resilience measure. In contrast, a 'Competent' organisation is one that has got measures in place and implemented in a level that allows the system to cope with the challenges. In addition to that, and in order to quantify the maturity level for quantitative analytical basis, a scoring system, based on expert judgment, has been defined for each maturity level ranging from 0–1 to 4–5 indicating Maturity 0 and Maturity 4, respectively.

3.2. Survey design

This study adopted a qualitative-quantitative surveying method for data collection aiming to investigate the perceptions of water professionals pre-during COVID-19. The data was collected via a structured questionnaire formed of four parts: (1) general instructions with an introduction about the survey and informed consent; (2) general information to characterize the company and the role of the participant (three open-ended questions); (3) specific information about the challenges induced or exacerbated by the COVID-19 pandemic in the companies' context (one checkbox question); and (4) specific information formed of six sections indicating the six key resilience elements of the self-assessment framework (total of 28 multiple-choice questions, each one with a statement and a scoring system). Further information about each part of the questionnaire can be found in Supplementary Material (Table S1).

Each element of Direction, Awareness, Alignment, Learning, Strengthening, and Assurance contains a varying number of statements (from four to six) to evaluate the performance of the water company. Of the 28 statements in part 4, 11 are specifically about the pandemic and 17 are divided into two scenarios (before and during the pandemic). Each statement has a scoring system (0–1, 1–2, 2–3, 3–4, and 4–5) used by the respondent to evaluate the level of agreement between the company's situation and the presented statement. Respondents were asked to score their responses for every statement on the given scale, where 0–1 indicates the worst situation (strongly disagreement) and 4–5 indicates the best situation (strongly agreement). Although some companies provide both water and sewerage services, the questionnaire was specifically designed around the provision of drinking water due to the key role of water supply in protecting public health during the COVID-19 pandemic.

The questionnaire was previously developed for the UK context and then updated for a Brazilian context. It was pre-tested on a small sample of respondents ($n = 3$) before dissemination to uncover problems and assure that questions are well-written and can meet the surveys' intended objectives. The English version of the questionnaire is available in the Supplementary Material.

The questionnaire's design was focused on making the questions clear and unambiguous to improve respondents' understanding. In part 4 of the questionnaire, brief explanations about the concepts and terms essential

Table 2
Resilience maturity scales.

Maturity 0	Maturity 1	Maturity 2	Maturity 3	Maturity 4
Immature	Aware	Developed	Competent	Excellent
No measures implemented.	Some basic level of measures implemented.	Majority of measures in place. Implementation remains a challenge.	Strong evidence of measures in place. Good level of implementation.	Excellent demonstration of the necessary measures needed. Very strong level of implementation.
Score 0–1	Score 1–2	Score 2–3	Score 3–4	Score 4–5

Source: SWS (2018).

for understanding were provided, as well as examples similar to real work situations. At the end of each section of part 4, a 'Comment' field was included to allow respondents to record any opinion or additional information.

All questions were defined as mandatory, so each participant could only proceed to the next part/section after providing all required answers. Filling in the 'Comment' field was defined as optional. Respondents were informed in part 1 about their voluntary role in the research and about the possibility of withdrawal at any stage.

3.3. Survey data sources and collection

The survey was web-based and online using QuestionPro survey software (Essentials account, https://www.questionpro.com/us) controlled and managed by the lead/corresponding author. A Portuguese version of the questionnaire was used in the survey. To improve the response rate, it was guaranteed that the identity of respondents and companies would be anonymised. Informed consent was obtained from each respondent who was assured of the voluntary and confidential nature of the study. No personal information was collected, except when voluntarily provided by the respondent to obtain survey feedback. The data were collected based on the Brazil's Law on Access to Information (Federal Law n° 12,527/2011, Brazil, 2011).

The invitation letters were distributed to 37 water companies located in different regions of the country to guarantee the outcomes enough represents the water sector across Brazil. To date, of these 37 water companies, 26 are state-owned companies (regional water provision) and 11 are local companies. Together, they provide drinking water to 56 % of Brazil's population (Brazil, 2021b). The invitation letters contained instructions informing the research purpose, the survey's access link generated by QuestionPro and also an editable text file version. The survey invitation was sent preferably through the Brazilian Citizens' Information Service (CIS) and by e-mail when requested by the water company. The survey was conducted from 10th May 2021 to 31th August 2021. This period of time was necessary to respect the response time of the CIS system, in accordance with the Federal Law n. 12,527/2011 (Brazil, 2011). In May 2021, Brazil had already suffered two waves of COVID-19 (Zeiser et al., 2022) and policy responses to the COVID-19 pandemic had been in place since 2020 (Capodeferro and Smiderle, 2020).

Only complete questionnaires were used to compose the results of this research. Questionnaires with empty entries were excluded, regardless of the percentage of valid responses. In total, the online questionnaire had 104 views and 29 responses. Of the 37 water companies invited to the survey, 14 sent the complete questionnaire, including ten state-owned companies and four local ones. These 14 water companies provide drinking water to about 58 million people in 10 states of Brazil (Brazil, 2021b). The experience of the local companies participating in this survey with WSS services ranged from 11 to 54 years, while the state-owned experience ranged from 10 to 53 years (Brazil, 2021b). Regarding the companies' size, the local companies have between 112 and 532 employees, while the state-owned have between 139 and 12,806 employees, according to SNIS 2020 data (Brazil, 2021b). Additional baseline information about the 14 water companies is available in the Supplementary Material (Table S4).

The stakeholders participating in this survey were chosen on the basis of their roles and responsibilities in the water company. The responses were requested from the top-level (e.g., president) or middle-level (e.g., superintendent) managers. These managers are expected to be involved in the company's planning process and strategy implementation (Engberg et al., 2015). Therefore, they would be the most qualified participants to assess the company's resilience maturity level. With the exception of one respondent who held the position of ombudsman, all respondents representing the companies performed managerial or planning-related roles (Supplementary Material, Table S3). Respondent's experience ranged from 8 months to 19 years and 79 % declared to have worked at the company for at least 5 years (mean = 8.33, SD = 5.64).

3.4. Survey analysis

The data identifying the company in part 2 of the questionnaire was used only to classify the responses into two groups (local and state-owned companies) and were removed from the data set during the analysis process. The identifying information was anonymised by replacing the companies' names with the identification number automatically generated by QuestionPro. The information collected in part 3 of the questionnaire was used to understand the challenges of the COVID-19 pandemic from the point of view of the water professionals participating in the survey. The results were analysed in aggregate form, and hence there is no risk of possible disclosures. All the data collected were used only for exclusively scientific purposes.

The data collected in part 4 of the questionnaire was used to assess the overall maturity level of local and state-owned companies according to the six evaluated components, as well as the maturity level for each component (Direction, Awareness, Alignment, Learning, Strengthening, and Assurance). The percentage of responses for each score (0–1, 1–2, 2–3, 3–4, and 4–5) was calculated to assess resilience maturity (Supplementary Material, Table S2).

Radar chart was used to visualize and compare the distribution of these percentages across the six components. The following comparative scenarios were defined to evaluate the local and state-owned companies' performance in response to COVID-19:

i. current scenario, considering the scores for the 28 criteria (i.e., the responses to all 28 statements from part 4 of the questionnaire) regarding the companies' situation during the pandemic;
ii. comparison between pre-COVID-19 and during COVID-19 scenarios, considering the scores for the 17 criteria regarding the companies' situation before and during the pandemic, respectively.

4. Results and discussion

4.1. Common COVID-19 challenges from the water professionals' perspective

To get a better understanding of the challenges induced or exacerbated by the COVID-19 pandemic in water companies, respondents were asked to select one or more options from those presented in the questionnaire. These options were based on challenges that emerged in the literature review (see Section 2.2). The last option of the checkbox question was "Other" to allow respondents to provide an alternative challenge not covered by the available options. Despite the different measures adopted at all levels of government to mitigate the impacts of the pandemic, some common challenges were reported by respondents (Fig. 4). All companies reported at least one challenge related to the COVID-19 pandemic.

In this survey, as has been previously reported in the literature, 'bad debt' stood out as a challenge for water companies (highlighted by 21 % of the survey respondents), followed by the 'emergency measures imposed by the government' to help combat the spread of COVID-19 (14 %). Similar results were obtained by Spearing et al. (2021) in a study conducted with 28 water utilities from the United States. In our study, revenue decrease was specifically reported by four companies (three local and one state-owned). One respondent from a local company highlighted that the "drastic decrease in revenue" affected the company's strategic investment plan. Notably, this respondent reported that the policy of no water shut-offs may have led many consumers to prioritise paying other bills, increasing non-payments. In Uganda, a study conducted from March to June 2020 showed that the presidential directive to suspend disconnections for non-paying may have influenced households' willingness to pay for water (Sempewo et al., 2021). Therefore, COVID-19 has affected not only the water sector's revenues and expenditures but also the consumer payment behaviour.

The aforementioned results suggest that the COVID-19 pandemic has mainly intensified the financial challenges faced by some Brazilian water companies. Cotterill et al. (2020) also identified 'finance' as a key theme that emerged from a questionnaire distributed to water sector employees

Responses		Challenges
9	21%	**Bad debt**
6	14%	**Emergency measures imposed by the government, such as the suspension of water cuts.**
5	12%	**Changes in water consumption pattern.**
5	12%	**Increased water consumption.**
5	12%	**Other (write which one):**
		Shortage of workers. Impossibility to hire new employees.
		Inability to carry out the strategic investment plan due to bad debt and drastic decrease in revenue. It is also observed that users who are able to pay their bills on time do not do so considering the suspension of cutting water service due to non-payment.
		The shortage of critical supplies. Drought.
4	10%	**Delays in works and/or service orders.**
4	10%	**Reduction in revenue.**
3	7%	**Lack of basic sanitation infrastructure in areas of social vulnerability.**
1	2%	**Lack of digital platforms to serve customers remotely.**
0	0%	**There was no challenge.**
42	**100%**	

Fig. 4. Main challenges of the COVID-19 pandemic from the point of view of professionals from the 14 water companies evaluated.

during the UK lockdown in 2020. Reduced demand from both industrial and commercial consumers, and reduced ability to pay water bills probably contributed to revenue loss, as well as changes in water service disconnection policy. Thus, governments must develop sustainable regulations and policy interventions that consider local-specific socio-economic attributes and address gaps in infrastructure funding (Sempewo et al., 2021; Spearing et al., 2021).

Other COVID-19-related challenges from the respondents' perspective were shortages of workers and critical supplies. Past experiences with the influenza pandemic have shown that labour and supply-chain crises are expected in the face of such disruption (van Atta and Newsad, 2009). Another respondent also reported the compound impact of drought and COVID-19 on water supply as a challenge. The effect of the COVID-19 pandemic on water scarcity has been observed in studies from other countries (see Section 2.2.2). These findings further support the ideas of Neal (2020) and Lawson et al. (2022), who described the COVID-19 pandemic as a "threat multiplier". As mentioned in the literature review, the interaction between the pre-COVID-19 shocks and stresses (e.g., limited financial capacity, weather hazards) and the threat of the pandemic has increased the complexity of the interconnected and interacting risks with the potential for cascading effects.

4.2. Resilience maturity levels of local and state-owned companies

The aggregate data obtained for local and state-owned companies through the structured questionnaire are reported using a radar chart view (see Supplementary Material Table S5 for the original dataset and Table S6 for descriptive statistics). Most state-owned companies scored a maturity level between 3 (total score 3–4, 35 %) and 4 (total score 4–5, 47 %), indicating a good level of definition and implementation of measures to enhance resilience (Fig. 5). These companies also demonstrated a more homogeneous pattern among the six resilience components (Supplementary Material, Fig. S1). Direction, Awareness, Alignment and Learning had more than 80 % of the scores between 3–4 and 4–5. Strengthening and Assurance had the highest percentage of responses on the maturity 2 (total score 2–3, 25 %) and, therefore, they are the components that most need to be developed to strengthen organisational resilience.

On the other hand, local companies participating in this survey had more distributed scores along different resilience maturity levels, ranging from 8 % (maturity 0) to 34 % (maturity 3). About 60 % of the total score was at maturities 3 (34 %) and 4 (26 %) levels (Fig. 5). They also had more disparities between the resilience components. The Direction element, which is related to setting resilience objectives and plans, had 31 % of responses at maturity 0 (score 0–1). Of the total responses for this element, 69 % were between maturity 0 (score 0–1) and 2 (score 2–3). In contrast, most scores for the Awareness element were between 3–4 (maturity 3, 25 %) and 4–5 (maturity 4, 55 %). Leaning and Assurance also had higher percentages of responses at maturity level 4 (score 4–5) when compared to the other components. Although these local companies had a good level of awareness regarding their vulnerabilities and pandemic threats, our survey indicated they were less mature in the development and implementation of resilience measures.

The results suggest that water companies operating at local level have a lower resilience maturity level, especially in those components related to resilience planning. The local companies that performed the resilience self-assessment of this survey are smaller than most of the state-owned companies (Supplementary Material, Table S4), which may explain the lower resilience maturity. It is noteworthy that the limited observations are not statistically sufficient to generalize the results to all Brazilian companies. However, the results are relatable due to the large number of small water utilities operating under local governments in Brazil. Of the 1,354 Brazilian providers, 97 % are local companies, but the 28 regional utilities, of which 26 are state-owned, supplied 75 % of the Brazilian urban population with drinking water in 2020. The total operating revenue was about R$ 54,891 million for Brazilian regional companies and R$ 16,889 million for local companies in 2020 ($ 10,702 million and $ 3,293, respectively; USD dollar exchange rate of June 14, 2022) (Brazil, 2021a).

Further evidence suggests that small and medium-size water companies may face more challenging issues with financial access, managerial and workforce skills, and ageing infrastructure (Brown et al., 2005; Janzen et al., 2017; Switzer et al., 2016). Therefore, local companies are usually more likely to follow a reactive planning approach rather than implementing proactive strategies in order to build adaptive capacity in long-term. Corrective actions, implemented as a short-term reactive response to shocks, do not contribute to long-term resilience and are unable to reduce exposure and vulnerability to unexpected events if not linked to proactive planning (Gude and Muire, 2021; Rasoulkhani et al., 2020). Thus, local companies need to improve their strategic planning to increase preparedness for response and recovery (Cotterill et al., 2020).

Direction, awareness, alignment and learning are more present in larger companies, mainly due to their financial ability, political influence, and more exposure to research studies and resources. Large companies are generally more established and have greater access to skilled labour and

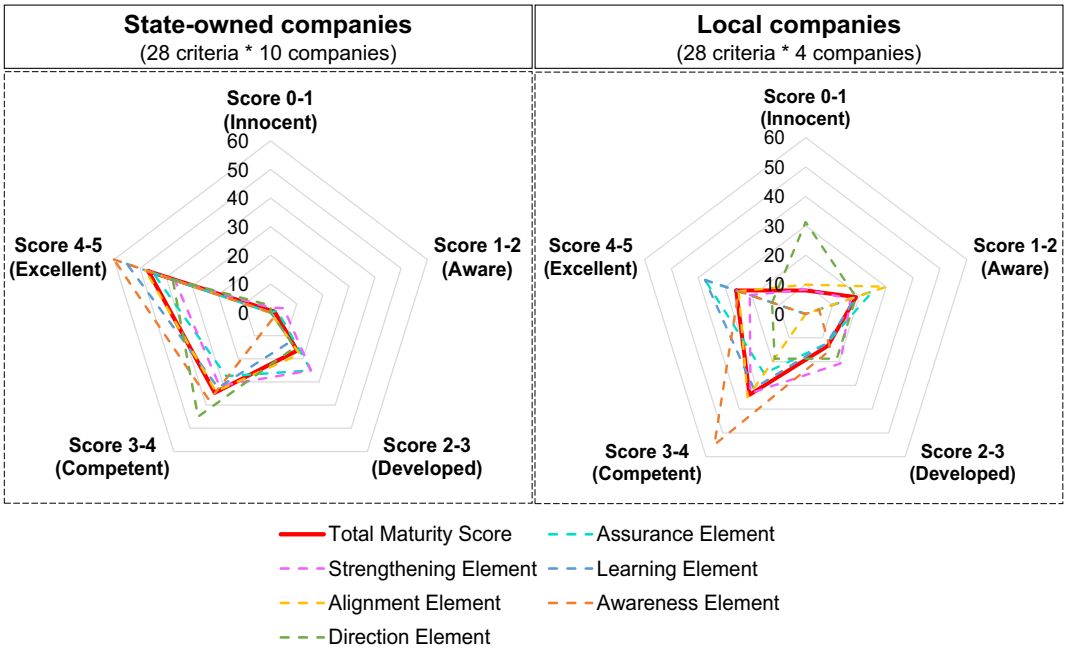

Fig. 5. Resilience maturity levels of local and state-owned companies according to the six evaluated components.

funding, compared to small companies (Bartik et al., 2020). They also have greater potential to generate profit due to economies of scale. It is worth mentioning that the results of this survey are preliminary and therefore, do not necessarily imply that state-owned companies perform better than local companies. Several state-owned companies did not respond to the questionnaire, and we argue that it is possible that those participating in this survey are the most aligned with resilience and the most concerned with transparency and continuous improvement of their processes.

Regarding the organisational response to the COVID-19 pandemic (Figs. 6 and 7), the local companies showed more contrasting scores assigned for the two situations (before and during the pandemic) than the state-owned counterparts. It was expected that those operating at the local level would be the most negatively impacted, as they were smaller than regional companies and with a less financial ability. Small businesses tend to be more vulnerable to financial crisis and other disruptions (Bartik et al., 2020). However, the COVID-19 pandemic seems to have brought about a positive change in the organisational resilience of the evaluated local companies. During the pandemic, they improved their score for maturities 3 (score 3–4) or 4 (score 4–5) in all components (Fig. 6), when compared to the pre-pandemic score. In the awareness component, the score for maturity 3 increased from 37 % to 63 %. This suggests that the COVID-19 crisis may have increased the consciousness levels and the companies' understanding about the potential risks to their operations.

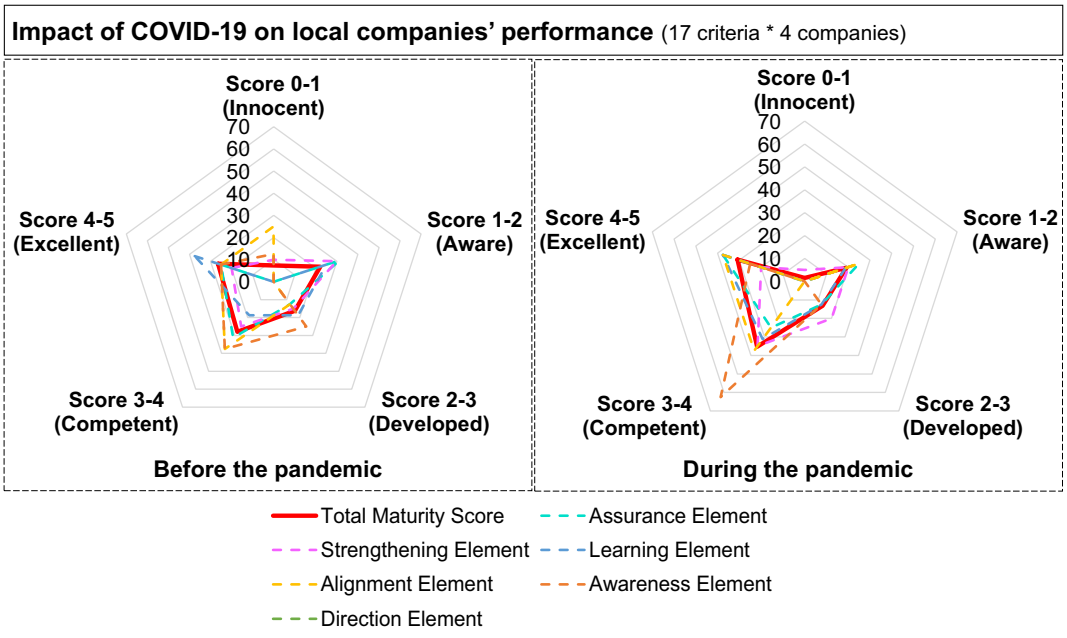

Fig. 6. Resilience maturity levels of the local companies before and during the pandemic.

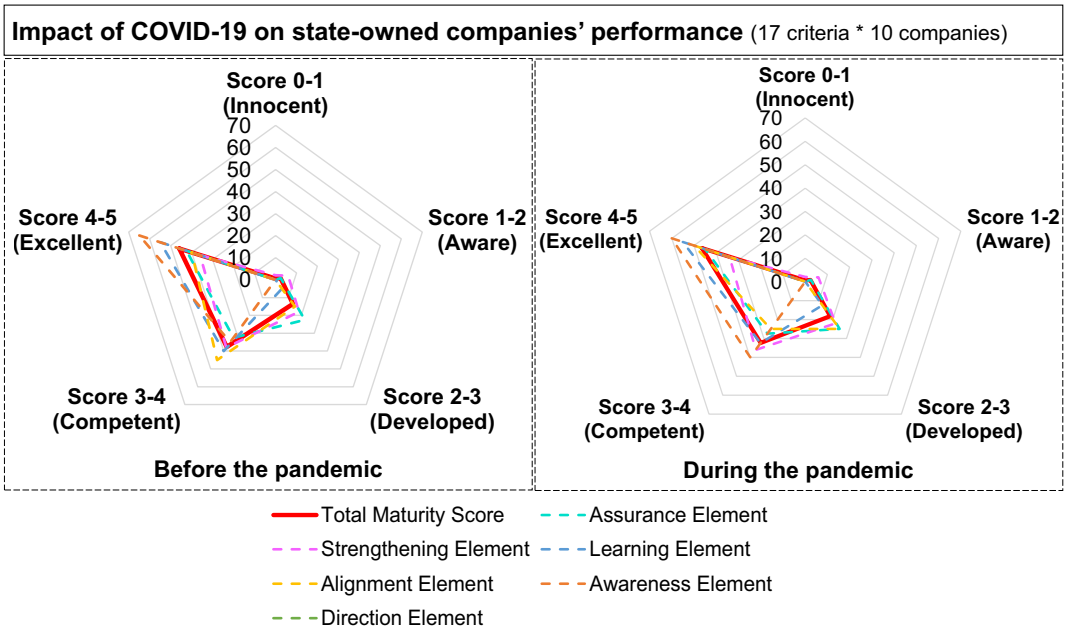

Fig. 7. Resilience maturity levels of the state-owned companies before and during the pandemic.

Regarding the state-owned companies, there is a small difference between the two scenarios (Fig. 7). The most interesting aspect of the data is that the variations indicate a small loss of performance of these companies, unlike what was observed for local companies. The total score for maturity 2 increased from 13 % (before the pandemic) to 18 % (during the pandemic), while the total score for maturity 3 decreased from 38 % to 32 %. Together, the scores for maturities 3 and 4 showed a reduction between 3 % and 10 % in alignment, learning, strengthening, and assurance. Alignment and learning were the most affected components for the state-owned companies evaluated during the COVID-19 crisis. The scores for maturity 2 increased by 10 % in alignment and 7 % in learning, indicating a loss of performance in aligning and sharing the companies' resilience objectives and adaptive capacity.

In summary, the results of this survey for local and state-owned companies provide important insights into the organisational resilience of Brazilian water companies in the face of a crisis. The state-owned companies showed a higher level of resilience maturity and, compared to local companies, were less affected by the COVID-19 pandemic. At the same time, the pandemic brought opportunities for improvement and learning, especially for the evaluated local companies. The COVID-19 pandemic proved how crucial staff/individual preparedness is to raise awareness and enable an organisation to respond effectively to a crisis. Both local and state-owned companies, however, require further 'strengthening' in terms of embedding resilience thinking into their solutions development. These findings, while preliminary, highlight the need for proactive emergency preparedness, as was also observed by Sowby (2020). Water companies, mainly those that do not have formal resilience measures in place (e.g., risk management process, crisis management strategy, business continuity plan), should learn from their response to COVID-19 and develop long-term strategies for increasing their resilience to future crisis. Also, more collaboration between the local and state-owned companies could be prioritised for knowledge and experience exchange.

5. Conclusion

This study identified several challenges of the water sector prior to COVID-19, and also the pressures induced or exacerbated during the COVID-19 pandemic. Moreover, a structured questionnaire was designed to confirm these COVID-19 challenges and assess the water sector performance against the six resilience elements from the UK Southern Water's framework for organisational resilience. The survey was conducted from May 2021 to August 2021. The main conclusions drawn from the observed results are as follows:

- Bad debt and the COVID-19 emergency measures are recognised as the main challenges by 21 % and 14 % of the survey respondents;
- The COVID-19 pandemic was identified as a "threat multiplier", particularly to already existing financial challenges;
- The COVID-19-related challenges has generated social, economic and environmental impacts and may lead to increased risk of water insecurity;
- The state-owned and local companies evaluated scored an almost similar maturity level 3, 35 % and 34 % respectively, while the local companies scored much lower at maturity level 4 i.e., 26 % as opposed to 47 % in state-owned sector. This indicates that COVID-19 has a greater impact on local companies and the needs to increase preparedness for response and recovery;
- The COVID-19 pandemic increased the risk perceptions of water sector professionals and provided opportunities for local water companies to improve their resilience maturity level;

The dataset collected in this survey was used to draw generalizability conclusions about local and state-owned companies' resilience maturity in Brazil, despite analysing a small subset of water companies. This survey was carried out in critical times in the water sector during Brazil's prolonged lockdown with knock-on effects on the water sector's activities. This impacted the number of responses received mainly due to staff's limited availability and reachability. Many water companies, especially local ones, still work mainly face-to-face and access via email is very difficult. Nevertheless, the type of participants who responded was fairly distributed and can be said that represent the sector and its approach. Future research should further confirm these initial findings by analysing water sector responses during the pandemic on a larger scale. It would also be important to consider the sewage-related issues in the face of COVID-19 in future studies. Moreover, future research could continue to explore how the companies' response to crisis related to their resilience maturity level.

CRediT authorship contribution statement

Karen Tavares Zambrano: Conceptualization, Investigation, Formal analysis, Writing - original draft.

Maryam Imani: Conceptualization, Methodology, Writing - review & editing.

Davi Gasparini Fernandes Cunha: Conceptualization, Validation, Writing - review & editing.

Ethical statement

This research does not require formal ethical review and approval under the Brazilian Resolution N° 510, of April 7, 2016 (Brazil, 2016). The dataset is anonymous, refers exclusively to public water companies' information, and the research only uses publicly available or opinion-based information without participants identification. The data were collected based on the Brazil's Law on Access to Information (Federal Law n° 12.527/2011). The results were analysed only in aggregate form, without the possibility of individual identification, and there are no risks of possible disclosures. All ethical principles were followed and participants were informed in the free and informed consent form about their role in the survey and the voluntary nature of their participation.

Data availability

The data supporting the findings of this study are available within the article and its supplementary material.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.scitotenv.2022.157637.

References

ABAR, 2020. Regulação Saneamento Básico 2020 [Basic Sanitation Regulation 2020] Brasília, DF, Brazil.

ABAR, 2020. Diretrizes ABAR: 20 recomendações regulatórias diante da pandemia [ABAR Guidelines: 20 regulatory recommendations in the face of the pandemic] Brasilia, DF, Brazil.

Abu-Bakar, H., Williams, L., Hallett, S.H., 2021. Quantifying the impact of the COVID-19 lockdown on household water consumption patterns in England. Npj clean Water 4, 13. https://doi.org/10.1038/s41545-021-00103-8.

Acter, T., Uddin, N., Das, J., Akhter, A., Choudhury, T.R., Kim, S., 2020. Evolution of severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) as coronavirus disease 2019 (COVID-19) pandemic: a global health emergency. Sci. Total Environ. 730, 138996. https://doi.org/10.1016/j.scitotenv.2020.138996.

Adeyeye, K., Gibberd, J., Chakwizira, J., 2020. Water marginality in rural and peri-urban communities. J. Clean. Prod. 273, 122594. https://doi.org/10.1016/j.jclepro.2020.122594.

Ahmed, F., Ahmed, N., Pissarides, C., Stiglitz, J., 2020. Why inequality could spread COVID-19. Lancet Public Health 5, e240. https://doi.org/10.1016/S2468-2667(20)30085-2.

Ahmed, F., Islam, M.A., Kumar, M., Hossain, M., Bhattacharya, P., Islam, M.T., Hossen, F., Hossain, M.S., Islam, M.S., Uddin, M.M., Islam, M.N., Bahadur, N.M., Didar-Ul-Alam, M., Reza, H.M., Jakariya, M., 2021. First detection of SARS-CoV-2 genetic material in the vicinity of COVID-19 isolation Centre in Bangladesh: variation along the sewer network. Sci. Total Environ. 776, 145724. https://doi.org/10.1016/j.scitotenv.2021.145724.

Aiello, A.E., Coulborn, R.M., Perez, V., Larson, E.L., 2008. Effect of hand hygiene on infectious disease risk in the community setting: a meta-analysis. Am. J. Public Health 98, 1372–1381. https://doi.org/10.2105/AJPH.2007.124610.

Ali, S.A., Parvin, F., 2022. Examining challenges and multi-strategic approaches in waste management during the COVID-19 pandemic: a systematic review. Waste Manag. Res., 0734242X2210793. https://doi.org/10.1177/0734242X221079303.

Angelov, N., Waldenström, D., 2021. COVID-19 and income inequality: evidence from monthly population registers. SSRN Electron. J. https://doi.org/10.2139/ssrn.3885421.

Antwi, S.H., Getty, D., Linnane, S., Rolston, A., 2021. COVID-19 water sector responses in Europe: a scoping review of preliminary governmental interventions. Sci. Total Environ. 762, 143068. https://doi.org/10.1016/j.scitotenv.2020.143068.

Artigo 19, 2020. Acesso à água e saneamento para enfrentar a COVID-19 no Brasil [Access to water and sanitation to face COVID-19 in Brazil] São Paulo.

ARUP, 2016. The Future of Urban Water São Paulo. Future of Urban Water. ARUP São Paulo, São Paulo, Brazil. https://www.arup.com/-/media/arup/files/publications/f/future_of_urban_water_sao_paulo_v7.pdf. (Accessed 5 October 2022).

ARUP, Anglian Water, 2018. A Framework for Resilience: PR19 and Beyond. ARUP and Anglian Water, London, UK. https://www.anglianwater.co.uk/siteassets/household/about-us/a-framework-for-resilience-pr19-and-beyond.pdf. (Accessed 10 May 2022).

Baldovin, T., Amoruso, I., Fonzo, M., Buja, A., Baldo, V., Cocchio, S., Bertoncello, C., 2021. SARS-CoV-2 RNA detection and persistence in wastewater samples: an experimental network for COVID-19 environmental surveillance in Padua, Veneto Region (NE Italy). Sci. Total Environ. 760, 143329. https://doi.org/10.1016/j.scitotenv.2020.143329.

Bandala, E.R., Kruger, B.R., Cesarino, I., Leao, A.L., Wijesiri, B., Goonetilleke, A., 2021. Impacts of COVID-19 pandemic on the wastewater pathway into surface water: a review. Sci. Total Environ. 774, 145586. https://doi.org/10.1016/j.scitotenv.2021.145586.

Barbier, E.B., Burgess, J.C., 2020. Sustainability and development after COVID-19. World Dev. 135, 105082. https://doi.org/10.1016/j.worlddev.2020.105082.

Barbosa, A., Brusca, I., 2015. Governance structures and their impact on tariff levels of Brazilian water and sanitation corporations. Util. Policy 34, 94–105. https://doi.org/10.1016/j.jup.2015.02.002.

Bartik, A.W., Bertrand, M., Cullen, Z., Glaeser, E.L., Luca, M., Stanton, C., 2020. The impact of COVID-19 on small business outcomes and expectations. Proc. Natl. Acad. Sci. 117, 17656–17666. https://doi.org/10.1073/pnas.2006991117.

Bogler, A., Packman, A., Furman, A., Gross, A., Kushmaro, A., Ronen, A., Dagot, C., Hill, C., Vaizel-Ohayon, D., Morgenroth, E., Bertuzzo, E., Wells, G., Kiperwas, H.R., Horn, H., Negev, I., Zucker, I., Bar-Or, I., Moran-Gilad, J., Balcazar, J.L., Bibby, K., Elimelech, M., Weisbrod, N., Nir, O., Sued, O., Gillor, O., Alvarez, P.J., Crameri, S., Arnon, S., Walker, S., Yaron, S., Nguyen, T.H., Berchenko, Y., Hu, Y., Ronen, Z., Bar-Zeev, E., 2020. Rethinking wastewater risks and monitoring in light of the COVID-19 pandemic. Nat.Sustain. 3, 981–990. https://doi.org/10.1038/s41893-020-00605-2.

Boretti, A., 2020. Covid19 pandemic as a further driver of water scarcity in Africa. GeoJournal https://doi.org/10.1007/s10708-020-10280-7.

Brazil, 2011. Federal Law n. 12,527. Regulates Access to Information and Takes Other Measures. President's Cabinet, Brasília, DF, Brazil.

Brazil, 2016. Brazilian Resolution N° 510, of April 7, 2016. Plenary of the National Health Council Published in the Official Gazette No. 98, Tuesday, May 24, 2016 - section 1, pages 44, 45, 46. Brasília, DF, Brazil.

Brazil, 2020. Federal Law n. 14026 of 15 July, 2020. President's Cabinet, Brasília, DF, Brazil sd.2149.

Brazil, 2021. The Ministry of Regional Development. National Sanitation Information System. Diagnóstico Temático Serviços de Água e Esgoto: Visão Geral, ano de referência 2020 [Thematic Diagnosis Water and Sewage Services: Overview, reference year 2020]. [WWW Document]. URL http://www.snis.gov.br/downloads/diagnosticos/ae/2020/DIAGNOSTICO_TEMATICO_VISAO_GERAL_AE_SNIS_2021.pdf (accessed 06.10.22).

Brazil, 2021. The Ministry of Regional Development. Série Histórica - Sistema Nacional de Informações sobre Saneamento [Historical Series - National Sanitation Information System] [WWW Document]. Informações e indicadores agregados de 2020 e 2021. URL http://app4.mdr.gov.br/serieHistorica/# (accessed 06.08.22).

Brown, B., Weersink, A., de Loë, R.C., 2005. Measuring financial capacity and the effects of regulatory changes on small water systems in Nova Scotia. Can.Water Resour. J. 30, 197–210. https://doi.org/10.4296/cwrj3003197.

BSI, 2014. BS 65000 [WWW Document]. Guidance on organizational resilience. https://www.bsigroup.com/en-GB/about-bsi/media-centre/press-releases/2014/november/Organizational-resilience-standard-published/.

Butler, D., Ward, S., Sweetapple, C., Astaraie-Imani, M., Diao, K., Farmani, R., Fu, G., 2017. Reliable, resilient and sustainable water management: the Safe & SuRe approach. Glob. Chall. 1, 63–77. https://doi.org/10.1002/gch2.1010.

Butler, G., Pilotto, R.G., Hong, Y., Mutambatsere, E., 2020. The Impact of COVID-19 on the Water and Sanitation Sector. IFC - International Finance Corporation.

Campos, M.A.S., Carvalho, S.L., Melo, S.K., Gonçalves, G.B.F.R., dos Santos, J.R., Barros, R.L., Morgado, U.T.M.A., da Silva Lopes, E., Abreu Reis, R.P., 2021. Impact of the COVID-19 pandemic on water consumption behaviour. Water Supply https://doi.org/10.2166/ws.2021.160.

Capodeferro, M.W., Smiderle, J.J., 2020. The Brazilian sanitation sector's response to COVID-19. Rev.Admin.Pública 54, 1022–1036. https://doi.org/10.1590/0034-761220200324x.

Chakraborty, I., Maity, P., 2020. COVID-19 outbreak: migration, effects on society, global environment and prevention. Sci. Total Environ. 728, 138882. https://doi.org/10.1016/j.scitotenv.2020.138882.

Chu, W., Fang, C., Deng, Y., Xu, Z., 2021. Intensified disinfection amid COVID-19 pandemic poses potential risks to water quality and safety. Environ. Sci. Technol. 55, 4084–4086. https://doi.org/10.1021/acs.est.0c04394 Rio de Janeiro, RJ, Brazil.

Cotterill, S., Bunney, S., Lawson, E., Chisholm, A., Farmani, R., Melville-Shreeve, P., 2020. COVID-19 and the water sector: understanding impact, preparedness and resilience in the UK through a sector-wide survey. Water Environ. J. 34, 715–728. https://doi.org/10.1111/wej.12649.

Cunha Libanio, P.A., 2020. Water reforms in Brazil: challenges and opportunities for promoting water security in a continental-sized country. World Water Policy 6, 230–245. https://doi.org/10.1002/wwp2.12042.

de Sousa, A.C.A., 2020. What to expect from the new sanitation framework? Cad. Saúde Pública 36. https://doi.org/10.1590/0102-311x00224020.
Defra, 2017. The Government's Strategic Priorities and Objectives for Ofwat, September 2017 [WWW Document]. URL https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/661803/sps-ofwat-2017.pdf (accessed 3.12.21).
Delen, D., Eryarsoy, E., Davazdahemami, B., 2020. No place like home: cross-national data analysis of the efficacy of social distancing during the COVID-19 pandemic. JMIR Public Health Surveill. 6, e19862. https://doi.org/10.2196/19862.
Diep, L., Martins, F.P., Campos, L.C., Hofmann, P., Tomei, J., Lakhanpaul, M., Parikh, P., 2020. Linkages between sanitation and the sustainable development goals: a case study of Brazil. Sustain. Dev. https://doi.org/10.1002/sd.2149 sd.2149.
Engberg, R., Hörte, S.-Å., Lundbäck, M., 2015. Strategy implementation and organizational levels: resourcing for innovation as a case. J. Org. Eff. People Perform. 2, 157–175. https://doi.org/10.1108/JOEPP-03-2015-0007.
Feizizadeh, B., Omarzadeh, D., Ronagh, Z., Sharifi, A., Blaschke, T., Lakes, T., 2021. A scenario-based approach for urban water management in the context of the COVID-19 pandemic and a case study for the Tabriz metropolitan area, Iran. Sci. Total Environ. 790 (148272). https://doi.org/10.1016/j.scitotenv.2021.148272.
Foladori, P., Cutrupi, F., Segata, N., Manara, S., Pinto, F., Malpei, F., Bruni, L., la Rosa, G., 2020. SARS-CoV-2 from faeces to wastewater treatment: what do we know? A review. Sci. Total Environ. 743, 140444. https://doi.org/10.1016/j.scitotenv.2020.140444.
Gallopín, G.C., 2012. Five stylized scenarios. Global Water Futures 2050. United Nations Educational, Scientific and Cultural Organisation, UNESCO, Paris, France.
Gheisi, A., Forsyth, M., Naser, Gh., 2016. Water distribution systems reliability: a review of research literature. J. Water Resour. Plan. Manag. 142, 04016047. https://doi.org/10.1061/(ASCE)WR.1943-5452.0000690.
Girón-Navarro, R., Linares-Hernández, I., Castillo-Suárez, L.A., 2021. The impact of coronavirus SARS-CoV-2 (COVID-19) in water: potential risks. Environ. Sci. Pollut. Res. 28, 52651–52674. https://doi.org/10.1007/s11356-021-16024-5.
Goldin, J., Nhamo, L., Ncube, B., Zvimba, J.N., Petja, B., Mpandeli, S., Nomquphu, W., Hlophe-Ginindza, S., Greeff-Laubscher, M.R., Molose, V., Lottering, S., Liphadzi, S., Naidoo, D., Mabhaudhi, T., 2022. Resilience and sustainability of the water sector during the COVID-19 pandemic. Sustainability 14, 1482. https://doi.org/10.3390/su14031482.
Gude, V.G., Muire, P.J., 2021. Preparing for outbreaks – implications for resilient water utility operations and services. Sustain. Cities Soc. 64, 102558. https://doi.org/10.1016/j.scs.2020.102558.
Haque, M., 2020. Handwashing in averting infectious diseases: relevance to COVID-19. J. Popul. Ther. Clin. Pharmacol. 27, e37–e52. https://doi.org/10.15586/jptcp.v27SP1.711.
Hirata, T., 2020. Saneamento já tem quase 25% de inadimplência [Sanitation already has almost 25% of bad debt] [WWW Document]. Aesbe website. URL https://aesbe.org.br/saneamento-ja-tem-quase-25-de-inadimplencia/ (accessed 3.1.21).
Hirose, R., Ikegaya, H., Naito, Y., Watanabe, N., Yoshida, T., Bandou, R., Daidoji, T., Itoh, Y., Nakaya, T., 2021. Survival of severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) and influenza virus on human skin: importance of hand hygiene in coronavirus disease 2019 (COVID-19). Clin. Infect. Dis. 73, e4329–e4335. https://doi.org/10.1093/cid/ciaa1517.
Hu, B., Guo, H., Zhou, P., Shi, Z.-L., 2021. Characteristics of SARS-CoV-2 and COVID-19. Nat. Rev. Microbiol. 19, 141–154. https://doi.org/10.1038/s41579-020-00459-7.
IBGE, 2020. Population estimates for the Brazilian municipalities and Federation Units on July 1, 2021 [WWW Document]. URL https://www.ibge.gov.br//en/statistics/social/population/18448-estimates-of-resident-population-for-municipalities-and-federation-units.html?=&t=resultados.
IBGE, 2020. Aglomerados Subnormais 2019: Classificação preliminar e informações de saúde para o enfrentamento à COVID-19 [Subnormal Agglomerates 2019: Preliminary classification and health information to cope with COVID-19] Rio de Janeiro, RJ, Brazil.
Islam, Md.A., Haque, Md.A., Rahman, Md.A., Hossen, F., Reza, M., Barua, A., Marzan, A.A., Das, T., Kumar Baral, S., He, C., Ahmed, F., Bhattacharya, P., Jakariya, Md., 2022. A review on measures to rejuvenate immune system: natural mode of protection against coronavirus infection. Front. Immunol. 13, 837290. https://doi.org/10.3389/fimmu.2022.837290.
ITB, 2019. Painel Saneamento Brasil [Brazil Sanitation Panel] [WWW Document]. Dados por localidade [Data by location]. URL https://www.painelsaneamento.org.br/localidade/index?id=0 (accessed 11.24.21).
Jakariya, Md., Ahmed, F., Islam, Md.A., Ahmed, T., Marzan, A.A., Hossain, M., Reza, H.M., Bhattacharya, P., Hossain, A., Nahla, T., Bahadur, N.M., Hasan, M.N., Islam, Md.T., Hossen, Md.F., Didar-ul-Alam, Md., Mow, N., Jahan, H., 2021. Wastewater based surveillance system to detect SARS-CoV-2 genetic material for countries with on-site sanitation facilities: an experience from Bangladesh (preprint). Epidemiology https://doi.org/10.1101/2021.07.30.21261347.
Janzen, A., Achari, G., Dore, M.H.I., Langford, C.H., 2017. Projecting financial capability in small Canadian drinking water treatment systems. J. Am. Water Works Assoc. 109, E440–E451. https://doi.org/10.5942/jawwa.2017.109.0113.
Johannessen, Å., Wamsler, C., 2017. What does resilience mean for urban water services? Ecol. Soc. 22, 1. https://doi.org/10.5751/ES-08870-220101.
Johns Hopkins University, 2021. COVID-19 Dashboard by the Center for Systems Science and Engineering (CSSE) [WWW Document]. URL https://coronavirus.jhu.edu/map.html (accessed 12.29.21).
Kalbusch, A., Henning, E., Brikalski, M.P., de Luca, F.V., Konrath, A.C., 2020. Impact of coronavirus (COVID-19) spread-prevention actions on urban water consumption. Resour. Conserv. Recycl. 163, 105098. https://doi.org/10.1016/j.resconrec.2020.105098.
Keulertz, M., Mulligan, M., Allan, J.A., 2020. The impact of COVID-19 on water and food systems: flattening the much bigger curve ahead. Water Int. 45, 430–434. https://doi.org/10.1080/02508060.2020.1779515.
Khatri, K., Vairavamoorthy, K., Porto, M., 2008. Challenges for urban water supply and sanitation in developing countries. In: Alaerts, G.J., Dickinson, N.L. (Eds.), Water for a Changing World - Developing Local Knowledge and Capacity. CRC Press, London, UK, pp. 81–100.
Kizhisseri, M.I., Mohamed, M.M., El-Shorbagy, W., Chowdhury, R., McDonald, A., 2021. Development of a dynamic water budget model for Abu Dhabi Emirate.UAE. PLOS ONE 16, e0245140. https://doi.org/10.1371/journal.pone.0245140.
Lahrich, S., Laghrib, F., Farahi, A., Bakasse, M., Saqrane, S., el Mhammedi, M.A., 2021. Review on the contamination of wastewater by COVID-19 virus: impact and treatment. Sci. Total Environ. 751, 142325. https://doi.org/10.1016/j.scitotenv.2020.142325.
Lawson, E., Farmani, R., Woodley, E., Butler, D., 2020. A resilient and sustainable water sector: barriers to the operationalisation of resilience. Sustainability 12, 1797. https://doi.org/10.3390/su12051797.
Lawson, E., Bunney, S., Cotterill, S., Farmani, R., Melville-Shreeve, P., Butler, D., 2022. COVID-19 and the UK water sector: exploring organizational responses through a resilience framework. Water Environ.J. 36, 161–171. https://doi.org/10.1111/wej.12737.
Luh, J., Royster, S., Sebastian, D., Ojomo, E., Bartram, J., 2017. Expert assessment of the resilience of drinking water and sanitation systems to climate-related hazards. Sci. Total Environ. 592, 334–344. https://doi.org/10.1016/j.scitotenv.2017.03.084.
Makropoulos, C., Nikolopoulos, D., Palmen, L., Kools, S., Segrave, A., Vries, D., Koop, S., van Alphen, H.J., Vonk, E., van Thienen, P., Rozos, E., Medema, G., 2018. A resilience assessment method for urban water systems. Urban Water J. 15, 316–328. https://doi.org/10.1080/1573062X.2018.1457166.
Mourad, K.A., 2020. A water compact for sustainable water management. Sustainability 12, 7339. https://doi.org/10.3390/su12187339.
Muduli, P.R., Kumar, A., Kanuri, V.V., Mishra, D.R., Acharya, P., Saha, R., Biswas, M.K., Vidyarthi, A.K., Sudhakar, A., 2021. Water quality assessment of the Ganges River during COVID-19 lockdown. Int. J. Environ. Sci. Technol. 18, 1645–1652. https://doi.org/10.1007/s13762-021-03245-x.
Neal, M.J., 2020. COVID-19 and water resources management: reframing our priorities as a water sector. Water Int. 45, 435–440. https://doi.org/10.1080/02508060.2020.1773648.
Norouzi, N., Zarazua de Rubens, G.Z., Enevoldsen, P., Behzadi Forough, A., 2021. The impact of COVID-19 on the electricity sector in Spain: an econometric approach based on prices. Int. J. Energy Res. 45, 6320–6332. https://doi.org/10.1002/er.6259.
OECD, 2015. Water Resources Governance in Brazil, OECD Studies on Water. OECD Publishing, Paris, France https://doi.org/10.1787/9789264238121-en.
OECD, 2020. The territorial impact of COVID-19: managing the crisis across level of government. OECD Policy Responses to Coronavirus (COVID-19).
OFWAT, 2015. Resilience Task & Finish Group Final Report. URL.
OFWAT, 2017. Resilience in the Round: Building Resilience for the Future. URL (accessed 06.10.22).
Osterrieder, A., Cuman, G., Pan-Ngum, W., Cheah, P.K., Cheah, P.-K., Peerawaranun, P., Silan, M., Orazem, M., Perkovic, K., Groselj, U., Schneiders, M.L., Poomchaichote, T., Waithira, N., Asarath, S., Naemiratch, B., Ruangkajorn, S., Skof, L., Kulpijit, N., Mackworth-Young, C.R.S., Ongkili, D., Chanviriyavuth, R., Mukaka, M., Cheah, P.Y., 2021. Economic and social impacts of COVID-19 and public health measures: results from an anonymous online survey in Thailand, Malaysia, the UK,Italy and Slovenia. BMJ Open 11, e046863. https://doi.org/10.1136/bmjopen-2020-046863.
Pagnoccheschi, B., 2016. Governabilidade e governança das águas no Brasil [Governability and water governance in Brazil]. In: de Moura, A.M.M. (Ed.), Governança Ambiental No Brasil: Instituições, Atores e Políticas Públicas. IPEA - Institute for Applied Economic Research, Brasília, DF, pp. 175–199.
Parikh, G., Rawtani, D., 2022. Environmental impact of COVID-19. URLCOVID-19 in the Environment. Elsevier, pp. 203–216 https://doi.org/10.1016/B978-0-323-90272-4.00001-4 (accessed 9.29.20).
Parikh, P., Diep, L., Gupte, J., Lakhanpaul, M., 2020. COVID-19 challenges and WASH in informal settlements: integrated action supported by the sustainable development goals. Cities 107, 102871. https://doi.org/10.1016/j.cities.2020.102871.
Patel, J.A., Nielsen, F.B.H., Badiani, A.A., Assi, S., Unadkat, V.A., Patel, B., Ravindrane, R., Wardle, H., 2020. Poverty, inequality and COVID-19: the forgotten vulnerable. Public Health 183, 110–111. https://doi.org/10.1016/j.puhe.2020.05.006.
Penteado, C.S.G., de Castro, M.A.S., 2021. Covid-19 effects on municipal solid waste management: What can effectively be done in the Brazilian scenario? Resources. Conservation and Recycling 164, 105152. https://doi.org/10.1016/j.resconrec.2020.105152.
Prado, T., Fumian, T.M., Mannarino, C.F., Maranhão, A.G., Siqueira, M.M., Miagostovich, M.P., 2020. Preliminary results of SARS-CoV-2 detection in sewerage system in Niterói municipality, Rio de JaneiroBrazil. Mem. Inst. Oswaldo Cruz 115, e200196. https://doi.org/10.1590/0074-02760200196.
Prado, T., Fumian, T.M., Mannarino, C.F., Resende, P.C., Motta, F.C., Eppinghaus, A.L.F., Chagas do Vale, V.H., Braz, R.M.S., Maranhão, A.G., Miagostovich, M.P., de Andrade, J. da S.R., 2021. Wastewater-based epidemiology as a useful tool to track SARS-CoV-2 and support public health policies at municipal level in Brazil. Water Res. 191, 116810. https://doi.org/10.1016/j.watres.2021.116810.
Quintuña, J., Marcelo, D., 2020. Estimated Impact of COVID-19 on Water Needs and Volume and Quality of Wastewater (SSRN Scholarly Paper No. ID 3651551). [WWW Document]. URLSocial Science Research Network, Rochester, NY (accessed 6.12.22).
Rahmasary, A.N., Robert, S., Chang, I.-S., Jing, W., Park, J., Bluemling, B., Koop, S., van Leeuwen, K., 2019. Overcoming the challenges of water, waste and climate change in Asian cities. Environ. Manag. 63, 520–535. https://doi.org/10.1007/s00267-019-01137-y.
Ramos, G., Hynes, W., 2020. A Systemic Resilience Approach to Dealing With Covid-19 and Future Shocks. Browse OECD Contributions. OECD Tackling Coronavirus (COVID-19).
Rasoulkhani, K., Mostafavi, A., Reyes, M.P., Batouli, M., 2020. Resilience planning in hazards-humans-infrastructure nexus: a multi-agent simulation for exploratory assessment of coastal water supply infrastructure adaptation to sea-level rise. Environ. Model Softw. 125, 104636. https://doi.org/10.1016/j.envsoft.2020.104636.

Rehak, D., Senovsky, P., Hromada, M., Lovecek, T., Novotny, P., 2018. Cascading impact assessment in a critical infrastructure system. Int. J. Crit. Infrastruct. Prot. 22, 125–138. https://doi.org/10.1016/j.ijcip.2018.06.004.

Renukappa, S., Kamunda, A., Suresh, S., 2021. Impact of COVID-19 on water sector projects and practices. Util. Policy 70, 101194. https://doi.org/10.1016/j.jup.2021.101194.

Rimoldi, S.G., Stefani, F., Gigantiello, A., Polesello, S., Comandatore, F., Mileto, D., Maresca, M., Longobardi, C., Mancon, A., Romeri, F., Pagani, C., Cappelli, F., Roscioli, C., Moja, L., Gismondo, M.R., Salerno, F., 2020. Presence and infectivity of SARS-CoV-2 virus in wastewaters and rivers. Sci. Total Environ. 744, 140911. https://doi.org/10.1016/j.scitotenv.2020.140911.

Rodina, L., 2019. Planning for water resilience: competing agendas among Cape Town's planners and water managers. Environ. Sci. Pol. 99, 10–16. https://doi.org/10.1016/j.envsci.2019.05.016.

SABESP, 2021. Press Releases: SABESP Results Center.

Saez, M., Tobias, A., Varga, D., Barceló, M.A., 2020. Effectiveness of the measures to flatten the epidemic curve of COVID-19. The case of Spain. Sci. Total Environ. 727, 138761. https://doi.org/10.1016/j.scitotenv.2020.138761.

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. Util. Policy 64, 101049. https://doi.org/10.1016/j.jup.2020.101049.

Sayeed, A., Rahman, M.H., Bundschuh, J., Herath, I., Ahmed, F., Bhattacharya, P., Tariq, M.R., Rahman, F., Joy, M.T.I., Abid, M.T., Saha, N., Hasan, M.T., 2021. Handwashing with soap: a concern for overuse of water amidst the COVID-19 pandemic in Bangladesh. Groundw. Sustain. Dev. 13, 100561. https://doi.org/10.1016/j.gsd.2021.100561.

Schultz, B., Uhlenbrook, S., 2008. Water security: what does it mean, what may it imply? In: Alaerts, G.J., Dickinson, N.L. (Eds.), Water for a Changing World - Developing Local Knowledge and Capacity. CRC Press, London, UK, pp. 41–56

Sempewo, J.I., Kisaakye, P., Mushomi, J., Tumutungire, M.D., Ekyalimpa, R., 2021. Assessing willingness to pay for water during the COVID-19 crisis in Ugandan households. Soc.Sci. Hum.Open 4, 100230. https://doi.org/10.1016/j.ssaho.2021.100230.

SIWI, UNICEF Brazil, The World Bank, 2020. Policy Brief - August 2020: The key role of Water, Sanitation and Hygiene Promotion in the response to Covid-19 in Brazil. [WWW Document]. URL https://www.unicef.org/brazil/media/9746/file/policy-brief-wash-in-response-to-covid-19.pdf (accessed 1.24.21).

Smiderle, J., Capodeferro, M., Fernandes, P., Gonçalves, E., Dutra, J., 2020. The governance of water and wastewater provision in Brazil: are there clear goals? Netw.Ind.Q. 22.

Sowby, R.B., 2020. Emergency preparedness after COVID-19: a review of policy statements in the U.S. water sector. Util. Policy 64, 101058. https://doi.org/10.1016/j.jup.2020.101058.

Spearing, L.A., Thelemaque, N., Kaminsky, J.A., Katz, L.E., Kinney, K.A., Kirisits, M.J., Sela, L., Faust, K.M., 2021. Implications of social distancing policies on drinking water infrastructure: an overview of the challenges to and responses of U.S. utilities during the COVID-19 pandemic. ACS ES&T Water 1, 888–899. https://doi.org/10.1021/acsestwater.0c00229.

Staddon, C., Everard, M., Mytton, J., Octavianti, T., Powell, W., Quinn, N., Uddin, S.M.N., Young, S.L., Miller, J.D., Budds, J., Geere, J., Meehan, K., Charles, K., Stevenson, E.G.J., Vonk, J., Mizniak, J., 2020. Water insecurity compounds the global coronavirus crisis. Water Int. 45, 416–422. https://doi.org/10.1080/02508060.2020.1769345.

Stepping, K., 2016. Urban sewage in Brazil: drivers of and obstacles to wastewater treatment and reuse. Governing the Water-Energy-Food Nexus Series. Deutsches Institut für Entwicklungspolitik (DIE), Bonn, Germany Discussion Paper, No. 26/2016 http://hdl.handle.net/10419/199489.

Stoler, J., Jepson, W.E., Wutich, A., 2020. Beyond handwashing: water insecurity undermines COVID-19 response in developing areas. J. Glob. Health 10. https://doi.org/10.7189/jogh.10.010355.

Sturgess, P., 2015. What is Resilience? https://doi.org/10.12774/eod_tg.may2016.sturgessandsparrey

Switzer, D., Teodoro, M.P., Karasik, S., 2016. The human capital resource challenge: recognizing and overcoming small utility workforce obstacles. J. Am. Water Works Assoc. 108, E416–E424. https://doi.org/10.5942/jawwa.2016.108.0093.

SWS, 2018. TA 7.8 Benchmarking Resilience and best practice - Annex on BS65000 [WWW Document]. https://www.southernwater.co.uk/media/2064/ta-078-benchmarking-resilience-and-best-practice-annex-on-bs65000.pdf.

Sypsa, V., Roussos, S., Paraskevis, D., Lytras, T., Tsiodras, S., Hatzakis, A., 2021. Effects of social distancing measures during the first epidemic wave of severe acute respiratory syndrome infection, Greece. Emerg. Infect. Dis. 27, 452–462. https://doi.org/10.3201/eid2702.203412.

The World Bank, 2020. COVID-19 in Brazil: impacts and policy responses. [WWW Document]. URL https://documents1.worldbank.org/curated/en/152381594359001244/pdf/Main-Report.pdf (accessed 6.12.22).

The World Bank, 2021. World Bank Country and Lending Groups [WWW Document]. URL https://datahelpdesk.worldbank.org/knowledgebase/articles/906519 (accessed 1.13.21).

Tobías, A., 2020. Evaluation of the lockdowns for the SARS-CoV-2 epidemic in Italy and Spain after one month follow up. Sci. Total Environ. 725, 138539. https://doi.org/10.1016/j.scitotenv.2020.138539.

UNDESA/PD, 2019. World Population Prospects 2019: Ten Key Findings New York.

UN-Habitat, 2003. The Challenge of Slums: Global Report on Human Settlements. Earthscan, London.

UN-Habitat, 2016. Slum Almanac 2015-2016: Tracking Improvement in the Lives of Slum Dwellers Nairobi.

United Nations, 2020. Economic Comission for Latin America and the Caribbean (ECLAC). N° 3 Special Report COVID-19: The social challenge in times of COVID-19. [WWW Document]. URL https://repositorio.cepal.org/bitstream/handle/11362/45544/1/S2000324_en.pdf (accessed 6.12.22).

United Nations, 2020. The Sustainable Development Goals Report 2020 [WWW Document]. URL https://unstats.un.org/sdgs/report/2020/ (accessed 9.29.20).

Urban, R.C., Nakada, L.Y.K., 2021. COVID-19 pandemic: solid waste and environmental impacts in Brazil. Sci. Total Environ. 755, 142471. https://doi.org/10.1016/j.scitotenv.2020.142471.

van Atta, P., Newsad, R., 2009. Water system preparedness and best practices for pandemic influenza. J. Am. Water Works Assoc. 101, 40–53. https://doi.org/10.1002/j.1551-8833.2009.tb09822.x.

Victral, D.M., Heller, L., 2021. The human rights to water and sanitation in policy responses to the COVID-19 pandemic: an analysis of Brazilian states. Water (Basel) 13, 228. https://doi.org/10.3390/w13020228.

Vitoria, R., Bressan, A., Iquiapaza, R., 2020. Do state-owned enterprises in Brazil require a risk premium factor? Braz.Bus.Rev. 17, 488–505. https://doi.org/10.15728/bbr.2020.17.5.1.

von Sperling, M., 2016. Urban wastewater treatment in Brazil. [WWW Document]. URLInter-American Development Bank (accessed 6.12.22) https://publications.iadb.org/publications/english/document/Urban-Wastewater-Treatment-in-Brazil.pdf.

Warren-Gash, C., Fragaszy, E., Hayward, A.C., 2013. Hand hygiene to reduce community transmission of influenza and acute respiratory tract infection: a systematic review. Influenza Other Respir. Viruses 7, 738–749. https://doi.org/10.1111/irv.12015.

WHO, UNICEF, 2020. Water, sanitation, hygiene, and waste management for SARS-CoV-2, the virus that causes COVID-19: Interim guidance. World Health Organization, Geneva, Switzerland. https://www.who.int/publications/i/item/WHO-2019-nCoV-IPC-WASH-2020.4. (Accessed 10 May 2022).

Zamhuri, S.A., Soon, C.F., Nordin, A.N., Ab Rahim, R., Sultana, N., Khan, M.A., Lim, G.P., Tee, K.S., 2022. A review on the contamination of SARS-CoV-2 in water bodies: transmission route, virus recovery and recent biosensor detection techniques. Sens.Bio-Sens.Res. 36, 100482. https://doi.org/10.1016/j.sbsr.2022.100482.

Zeiser, F.A., Donida, B., da Costa, C.A., Scherer, J.N., Barcellos, N.T., Alegretti, A.P., Ikeda, M.L.R., Müller, A.P.W.C., Bohn, H.C., Santos, I., Boni, L., Ramos, G.de O., Antunes, R.S., Righi, R.da R., Rigo, S.J., 2022. First and second COVID-19 waves in Brazil: a cross-sectional study of patients' characteristics related to hospitalization and in-hospital mortality. Lancet Reg. Health Am. 6, 100107. https://doi.org/10.1016/j.lana.2021.100107.

Zimmerman, J.B., Mihelcic, J.R., Smith, J., 2008. Global stressors on water quality and quantity. Environ. Sci. Technol. 42, 4247–4254.

Zumla, A., Niederman, M.S., 2020. The explosive epidemic outbreak of novel coronavirus disease 2019 (COVID-19) and the persistent threat of respiratory tract infectious diseases to global health security. Curr. Opin. Pulm. Med. 26, 193–196. https://doi.org/10.1097/MCP.0000000000000676.