Intermittent water supply systems and their resilience to COVID-19: IWA IWS SG survey

R. Farmani, Joe Dalton, Bambos Charalambous, Elizabeth Lawson, Sarah Bunney and Sarah Cotterill

ABSTRACT

There is limited information about the current state of intermittent water supply (IWS) systems at the global level. A survey was carried out by the Intermittent Water Supply Specialist Group of the International Water Association (IWA IWS SG) to better understand the current state of these systems and challenges that water companies may have faced under COVID-19 pandemic and to capture successful management strategies applied by water utilities. The survey consisted of three parts: (1) general information about IWS systems, (2) current state of IWS and (3) resilience of IWS under COVID-19 conditions, as well as some questions about potential interventions in order to improve system performance in general and under future uncertain conditions. The survey responses were evaluated based on the Safe & SuRe resilience framework, assessing measures of mitigation, adaptation, coping and learning, and exploring organisational and operational responses of IWS utilities. Infrastructure capacity and water resources availability were identified as the main causes of intermittency in most water distribution systems, while intermittent electricity was considered as the main external cause. Participants indicated that some risk assessment process was in place; however, COVID-19 has surpassed any provisions made to address the risks. Lessons learnt highlighted the importance of financial resources, e-infrastructure for efficient system operation and communication with consumers, and the critical role of international knowledge transfer and the sharing of best practice guidelines for improving resilience and transitioning towards continuous water supply.

Key words | conversion, COVID-19, equity, intermittent water supply systems, resilience, SDGs

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HIGHLIGHTS

- Impact of COVID-19 surpassed any provisions based on risk assessment approaches.
- Changes in intermittent energy supply had cascading positive and negative impacts.
- Inadequate infrastructure and financial strains are the main barriers to change.
- Sharing knowledge and strategic guidelines can accelerate utilities' resilience.
- Transition to 24/7 supply requires technical, financial and human resources support.

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INTRODUCTION

About 2.2 billion people worldwide lack access to safely managed drinking water (WHO/UNICEF 2019). This includes 1.3 billion with intermittent access (Charalambous & Laspidou 2017). In Target 7.C of the Millennium Development Goals (UN 2014), the focus was on infrastructure delivery to facilitate access to improved drinking water sources. Between 1990 and 2015, 2.6 billion people gained access to improved drinking water sources (UN MDG Monitor 2017). This meant that 1.9 billion people gained access to piped water (UN MDG Monitor 2017), but there are vast inequalities in the accessibility, availability and quality of water services (i.e. in some cases this is intermittent access). An intermittent water supply (IWS) system is defined as a piped water supply, which exposes some or all consumers to times without water supply on a regular basis. These systems can be found in South Asia, Latin America (Vairavamoorthy *et al.* 2008) and Africa (WHO & UNICEF 2000). There are different reasons why utilities may consider operating the water infrastructure under these conditions. These may include natural, technical and financial scarcity as well as user behaviour (Totsuka *et al.* 2004; Galaitsi *et al.* 2016; Simukonda *et al.* 2018a; Taylor *et al.* 2019). Intermittency could be daily, seasonal or occasional. The supply schedule varies a great deal in different locations; consumers could be without water for several hours in a day or several days in a week. The pattern of supply could be fixed, variable or unreliable. Operating water systems intermittently have a great deal of negative consequences for utilities, consumers and society at large including: rapid asset deterioration, more leaks and bursts (Klingel 2012), water quality issues (Kumpel & Nelson 2016), loss of income for utilities, inequity (Gullotta *et al.* 2020), financial burden for consumers (Burt *et al.* 2018) and public health (Ercumen *et al.* 2014; Bivins *et al.* 2017).

In the Sustainable Development Goals (SDGs), there is a requirement of a paradigm shift with a focus on sustainable service delivery. Intermittent water systems are very complex, and their efficient operation and management in order to deliver equitable supply to all the consumers remains a major challenge. The technical, social, financial and institutional challenges are exacerbated when multiple stressors affect the water systems simultaneously. Outbreaks of disease magnify these challenges of IWS systems. Previous to the COVID-19 pandemic, other outbreaks have demonstrated the importance of access to safe drinking water in strengthening resilience, promoting economic stabilisation and recovery of communities (ILO 2016). The full impact of COVID-19 on the water sector remains unclear. However, constraints such as water resources (Abolnga 2020), infrastructure capacity, social distancing and financial burdens could negatively impact the ability of water infrastructure to function successfully (Simukonda *et al.* 2018b). Delivery of safely managed water services has significant health, environmental and economic benefits. Cotterill *et al.* (2020) highlighted that the resilience of the economy and wider society to the COVID-19 pandemic largely depends on key workers and organisations to respond to, and adapt, in order to maintain performance of key services such as water systems.

A recent report by UN shows that countries that had made more progress in achieving the SDG6 (access to clean water) had more success in mitigating the COVID-19 risk (UN 2020a). It is widely acknowledged that without progress on SDG6 – to ensure availability and sustainable management of water and sanitation for all by 2030 – the other SDG goals and targets cannot be achieved, due to high interdependencies between different goals (UN-Water 2016). The UN (2020b) has launched the SDG6 Global Acceleration Framework to improve progress on SDG6; as at the current rate, the targets will not be achieved by 2030. The framework has a number of pillars including that of 'Accelerate'. The five accelerators include optimised financing, improved data and information, capacity development, innovation and governance. The practitioners and utilities have the ability to impact millions of residents by improving water supply provision, which in turn can deliver multiple benefits across several SDGs.

The COVID-19 pandemic has emphasised that ensuring safe and reliable water services is critical. COVID-19 presents an opportunity to strategically rethink the way IWS systems are managed to enhance the effectiveness of resilience strategies – Resistance, Reliability, Redundancy and

Response – in the water sector (UK Cabinet Office 2013), to react to and absorb the short- and medium-term impacts of COVID-19. This could be done by assessing water utilities' experiences before and during the COVID-19 pandemic to understand their technical, financial and social challenges, and provide learnings to minimise the impacts of similar events in the future, without jeopardising achievement of long-term environmental (natural resources) and economic (sustainable capital investment) goals. The focus will be on efficient operation and management of water systems, ensuring contribution to improved water availability, accessibility and affordability, while supporting long-term sustainable and resilient water systems by transition to continuous supply of water. Such systems will be able to bounce back after disaster (SDG9), improve the level of service for all users and enhance social equity (SDG10), and alleviate public health-related issues (SDG3) associated with lack of water or poor water quality.

The survey was carried out to understand key challenges and to capture successful strategic, tactical and operational management practices applied by water utilites operating under IWS conditions in the context of the COVID-19 pandemic. Based on the needs of different local settings, the challenges and knowledge gaps (understanding the dynamics of water demand, water quality, tariff systems, availability of alternative resources and supply systems, supply chain issues, shortage of skilled personnel and opportunities for digitalisation, and technical capabilities) were identified.

METHODS

The main aim of the survey was to understand the resilience of water utilities before and during the COVID-19 pandemic. The focus was on in-depth understanding of the issues, key challenges/barriers, capabilities and needs at each local context considering data/tool availability and technological, and financial and policy constraints. This information is a prerequisite to propose interventions to improve their performance and assess progress towards the SDGs. The topics included optimum operation and management of water systems, equity and affordability, digitalisation or remote monitoring and management systems, supply chain challenges, etc. The survey was designed by the University of Exeter's research team and members from IWA's IWS specialist group. Some of the questions were open response, while others were multiple choices with an option to provide additional information (Table 1). The main focus of the survey was capturing challenges, responses and impacts of COVID-19 before and during the lockdown, and gathering projections for after lockdown.

The survey questions were prepared based on the resilience framework that was developed as part of a research project, Safe & SuRe (Butler *et al.* 2017). The purpose of the resilience framework is to develop sustainable and resilient solutions for urban water management at a time of global uncertainty (Figure 1). It provides a platform to understand resilience by linking threats to consequences and to assess how strategies and interventions can enhance resilience. This involves the assessment and review of mitigation, adaptation, coping and learning related to resilient intervention measures at different local settings.

The framework facilitates analysis from different directions: top-down (risk-based), bottom-up (emergency planning) and middle-based (comprehensive resilience assessment with no knowledge of the threats) (Figure 2). It enables the identification of critical components and supports the development of key strategies for intervention to increase resilience (Meng *et al.* 2018).

The participants were contacted via IWA's IWS group members' mailing list (around 200 members), or IWS specialist group's committee members (23 members) contacted via the wider IWS community through their personal contacts (e.g. LinkedIn). The responses were collected from water utilities which have IWS or individuals who are working on IWS systems.

RESULTS

Survey responses

In all, 63 responses were received. Only 25 responses were considered in the analysis of the survey as other responses were incomplete. The main observation from the incomplete responses was that a majority of them stopped at the

Table 1 | Question phrasing and modality in the survey

Questions	Response type
Part 1: General information	
Your gender	Multiple choice
Participant's country	Open response
Type of organisation	Multiple choice
Participant's job	Multiple choice
Have you had essential worker status during COVID-19?	Multiple choice
Part 2 – Current state of IWS	
What is the state of IWS in your country?	Open response
What are the main causes of intermittency in your country?	Multiple choice
What type of IWS does your organisation deal with?	Multiple choice
What type of issues were you dealing with in your operation of IWS system prior to COVID-19?	Multiple choice
Are there any plans in place to convert the system into continuous supply?	Multiple choice
Part 3 – Resilience of IWS under COVID-19	
What did your organisation do to prepare (mitigation)?	Open response
Are there any steps that your organisation had taken previously that you think has helped with the response?	Open response
Has COVID-19 caused changes in the intermittency of supply?	Open response
Were there any unanticipated challenges?	Open response
How did your organisation respond (adaptation)?	Open response
Has your organisation noticed a change in customer behaviours?	Open response
Has your organisation noticed a change in NRW?	Open response
Do you have any specific examples of coping mechanisms that your organisation has used that have been successful and effective?	Open response
What are the lessons learnt from preparing for COVID-19?	Open response
How will your organisation adapt in the medium term?	Open response
What challenges might you face in adapting working practices?	Open response
How might this crisis change your future operations?	Open response
Do you think this crisis will change investment priorities in resilience?	Open response
Is more strategic guidance needed to support water companies through this crisis and beyond?	Open response
What role should international collaboration play in addressing future challenges?	Open response

beginning of part 2 of the questionnaire. This indicates that the willingness to contribute was there; however, a probable lack of quantitative information about these systems prevented the completion of the survey. Twenty-five responses are not large enough to be able to generalise the findings of this survey. However, the participants have suggested that knowledge transfer and learning from best practice is a requirement in order to make progress in improving or converting these systems from intermittent to continuous supply. This makes the survey even more relevant and highlights why such surveys and data collection are important for IWS systems.

Analysis of responses in part 1 – general information

Geographical distribution of participants

Figure 3 shows the geographical location of participants. The distribution of participation and number of participants

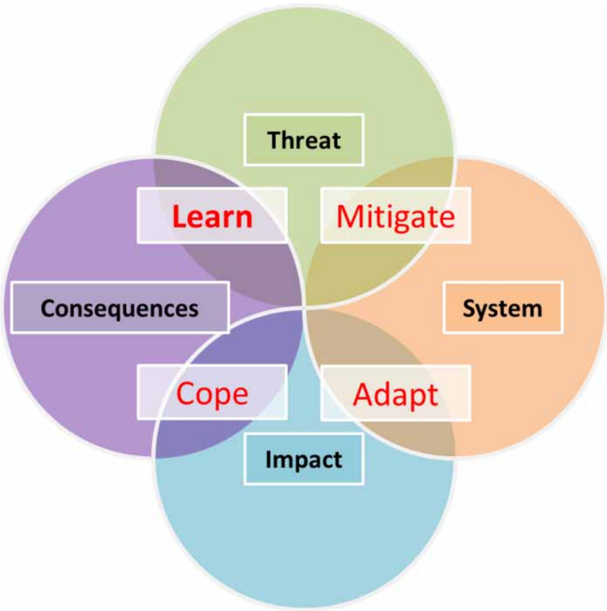

Figure 1 | The Safe & SuRe intervention framework (after Butler et al. 2017).

(presented in brackets), based on regions most affected by the IWS (IWS Strategic Plan 2020), are as follows:

- Latin America (Brazil (1), Mexico (2))
- Middle East and North Africa (Iran (1), Iraq (1), Jordan (1), Lebanon (2), Palestine (1))
- Sub-Saharan Africa (Kenya (1), Zambia (2), Zimbabwe (2))
- China and Central Asia (Nepal (1))
- Indian subcontinent (India (4))
- Asia Pacific (Philippines (1), Malaysia (1))

There was one response from a participant working in utility in Romania. One response was from France (research institute) and one from Portugal in which the participant was from a technology supplier organisation. Finally, one response was from an academic who did not disclose in which location they work. The incomplete responses were from countries including Argentina, Bolivia, Croatia, India, Kenya, Myanmar, Peru and Senegal.

Types of organisations and participants' profiles

The participants work in a range of organisations (Consultancy (4), Government Organisation (6), Development Bank (1), Regulator (1), Utility (3), Technology supplier (2), University (6) and Research Institute (2)) (Figure 4) with a wide range of responsibilities (Director, Engineer, Financial manager, Non-Revenue Water (NRW) manager, Hydraulic analyst, and Academic and Researcher). Eight of the participants were female and 17 were male, while 44% of them had essential workers status since lockdown.

Analysis of responses in part 2 – current state of the IWS

Population on IWS, duration and pattern of supply

Table 2 summarises the responses to the questions on % population in the country that are on IWS, and the duration and pattern of supply in part 2 of the questionnaire. There is a large variation from one country to another on level of accessibility and duration and pattern of water supply. The variation is visible even within a country, as demonstrated by different responses (for example, for India and Zimbabwe).

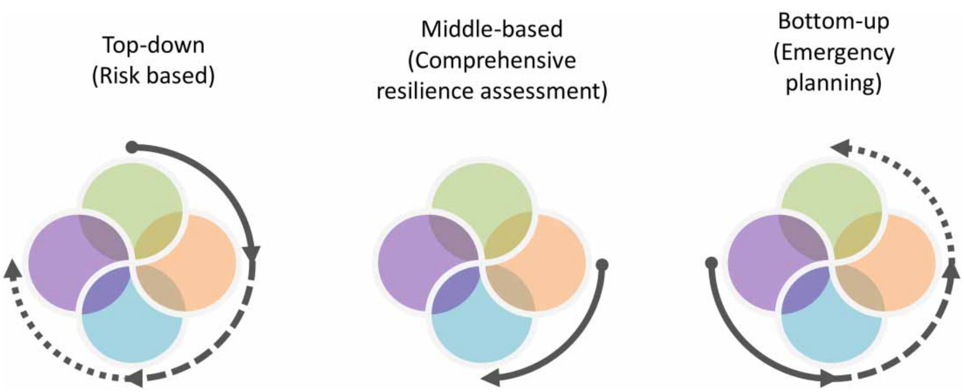

Figure 2 | Alternative management strategies using the Safe & SuRe Framework (after Butler et al. 2017).

Figure 3 | Geographical distribution of responses (upside down water drops with circle in the middle represent complete responses and circles with square in the middle represent incomplete responses).

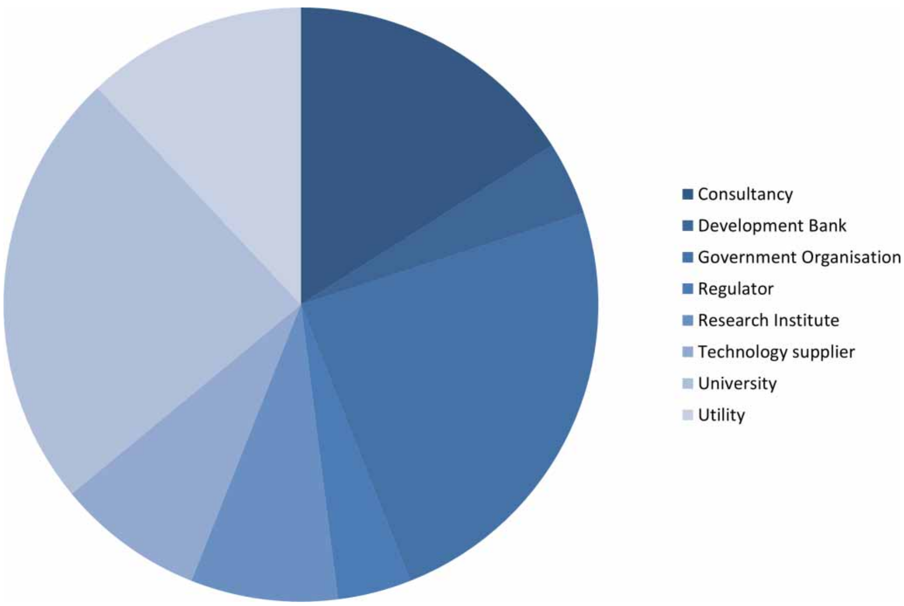

Figure 4 | Participating organisations.

Table 2 | Current state of IWS in different countries*

Country	% population of IWS	Duration and pattern of supply	Additional information
India	100	2–4 hours	
Jordan	100	Twice per week	
Lebanon	100		
Palestine	100		
Philippines	100	On average 19 hours	
India	95		
India	95		
Zimbabwe	90	8 hours, 4 times per week	
Kenya	80	6–48 hours per week	
Mexico	73		
Mexico	69		50% with pressure deficiency
Zimbabwe	60	12 hours every other day	
Nepal	58	1 hour daily or 1–3 hours weekly/every 15 days	
Zambia	55	5 hours	
India	40		
Iraq			High percentage of population on IWS
Iran			20% of rural area and a few cases in urban area
Malaysia			Occasionally
Portugal			5% with no access to the piped water system
Romania			Small communities
Zambia			No official data

*Four participants (Brazil, Lebanon, France and unknown location) did not disclose any information about the scale of intermittency in the IWS systems that they are involved. Blank cells indicate that information was not provided.

Type of IWS systems

The types of supply pattern of IWS systems in 23 participants' countries (two participants did not disclose this information) can be categorised as:

- Fixed (9 cases) – the supply time and volume of water are known
- Variable (9 cases) – the supply time is not known, but the volume of water is known
- Unreliable (2 cases) – the supply time and volume of water are not known
- Seasonal (3 cases) – during dry seasons

This shows that even the limited access to water is not guaranteed in more than 50% of cases.

Factors contributing to intermittency of supply

Figure 5 shows responses of the participants to the question on the causes of intermittency in different countries. Infrastructure capacity and limited availability of water resources have been mentioned as two main causes of intermittency in the majority of countries. Inadequate maintenance and asset management, inefficient operation of the water system and lack of financial resources have been considered by around 40% of participants as reasons for intermittency in distribution networks. 33% of participants indicated external factors such as intermittent electricity as a reason for IWS in their country. This indicates a cascading failure where an external failure is causing failure or having impact in the water distribution system. Contrary to the general belief that user behaviour

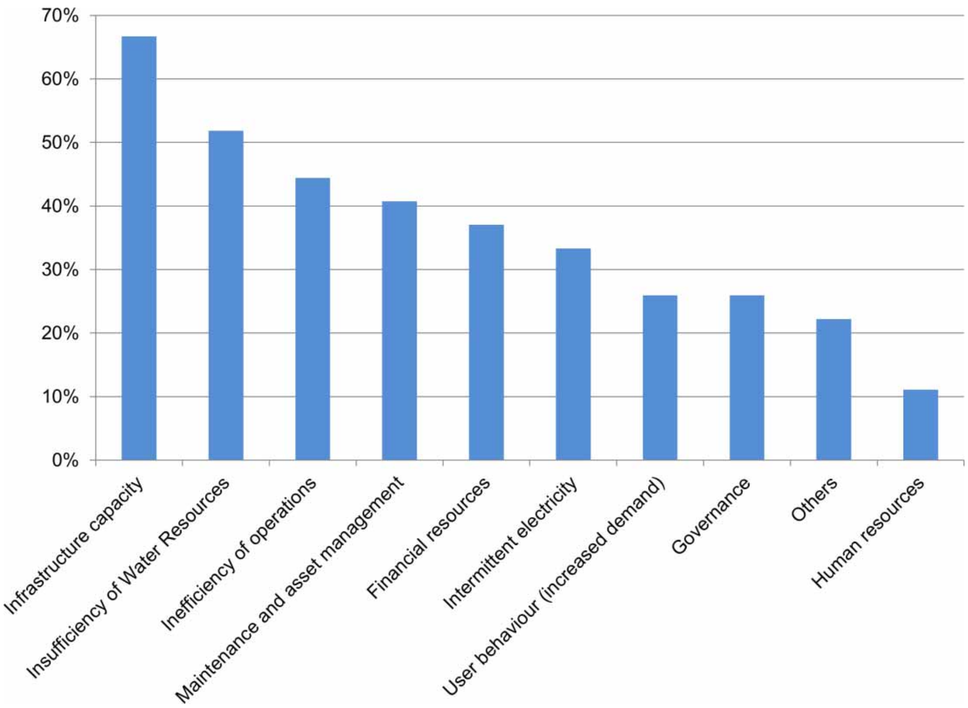

Figure 5 | Main causes of IWS.

and governance are key factors in intermittency in water distribution network, only 25% of participants indicated these as the main reason. Human resources were chosen by only 10% of participants as one of the factors causing intermittency. Some participants indicated population growth, raw water quality, under-capacity supply system, poor management, distribution losses, ageing infrastructure and vandalism as other factors causing intermittency in the system.

Issues with operation of IWS systems prior to COVID-19

Figure 6 shows the issues that participants were dealing with prior to the COVID-19 pandemic. The figure shows that leakage and insufficient pressure in the systems were the main issues that the majority of participants were dealing with.

Transition to the continuous supply system

While in some countries there are plans to convert distribution systems to continuous supply (e.g. 50 cities in India indicated by one of the participants from India), in some others financial support is being sought in order to do the conversion and there are no such plans in some other countries. Twelve participants indicated that there is a plan in their country to covert the system to continuous supply, while six said there are no plans and seven were not sure (Figure 7).

Different measures are being implemented, such as developing alternative water sources, increasing treatment plant capacity, rehabilitating of mains, creating district metered area (DMA), metering, pressure management at DMA levels in order to reduce real and apparent losses, in order to increase hours of supply or move towards continuous supply systems. A number of participants raised concerns regarding the slow speed of the rate of implementation, which was surpassed by the rate of population growth. Also, a lack of participatory methods in the decision-making process (i.e. not involving local stakeholders in the planning process by consultants) was mentioned as the reason for the failure of some of these plans, for example, planning conversion in locations where there is not enough water resources available.

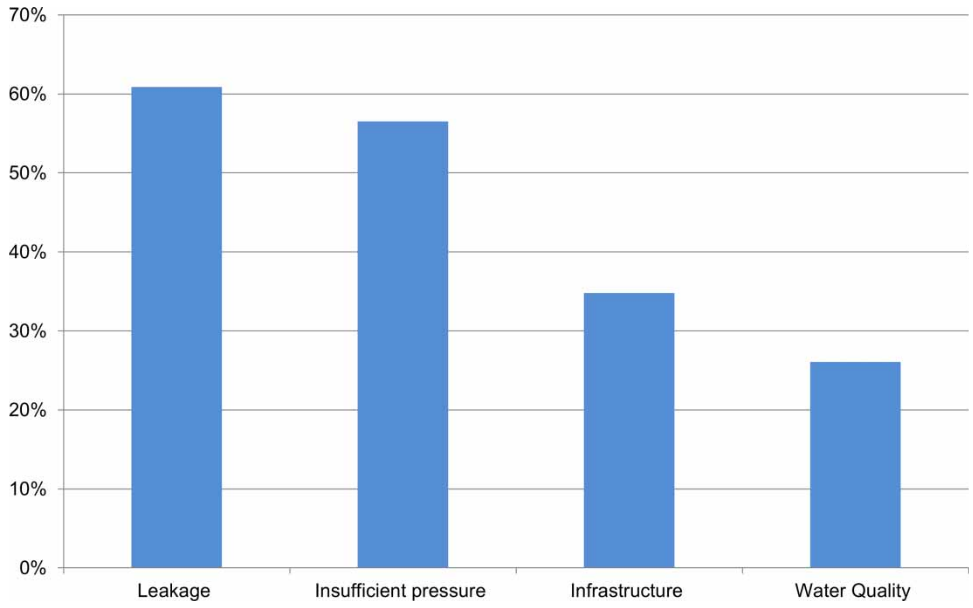

Figure 6 | Issues with the operation of IWS.

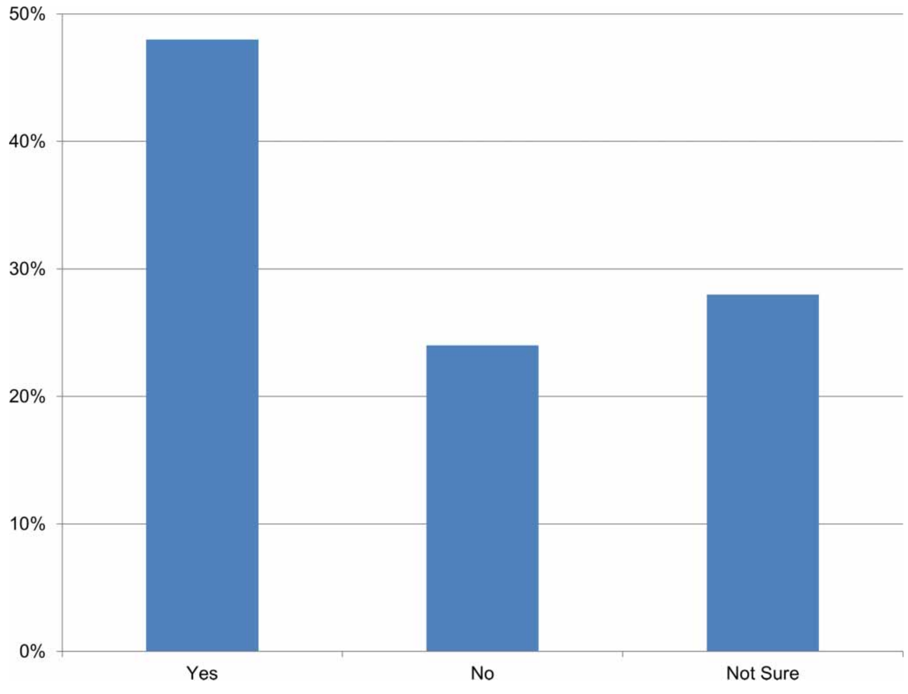

Figure 7 | Response to question on plans for conversion to continuous supply.

Analysis of responses in part 3 – state of IWS systems under COVID-19

The Safe & SuRe framework was used to analyse responses on the state of IWS during the COVID-19 pandemic. Interventions identified and implemented with the aim of increasing system resilience have been mapped onto the framework with results displayed in Figure 8.

The framework has been applied using the top-down approach with the threat of COVID-19 initially identified.

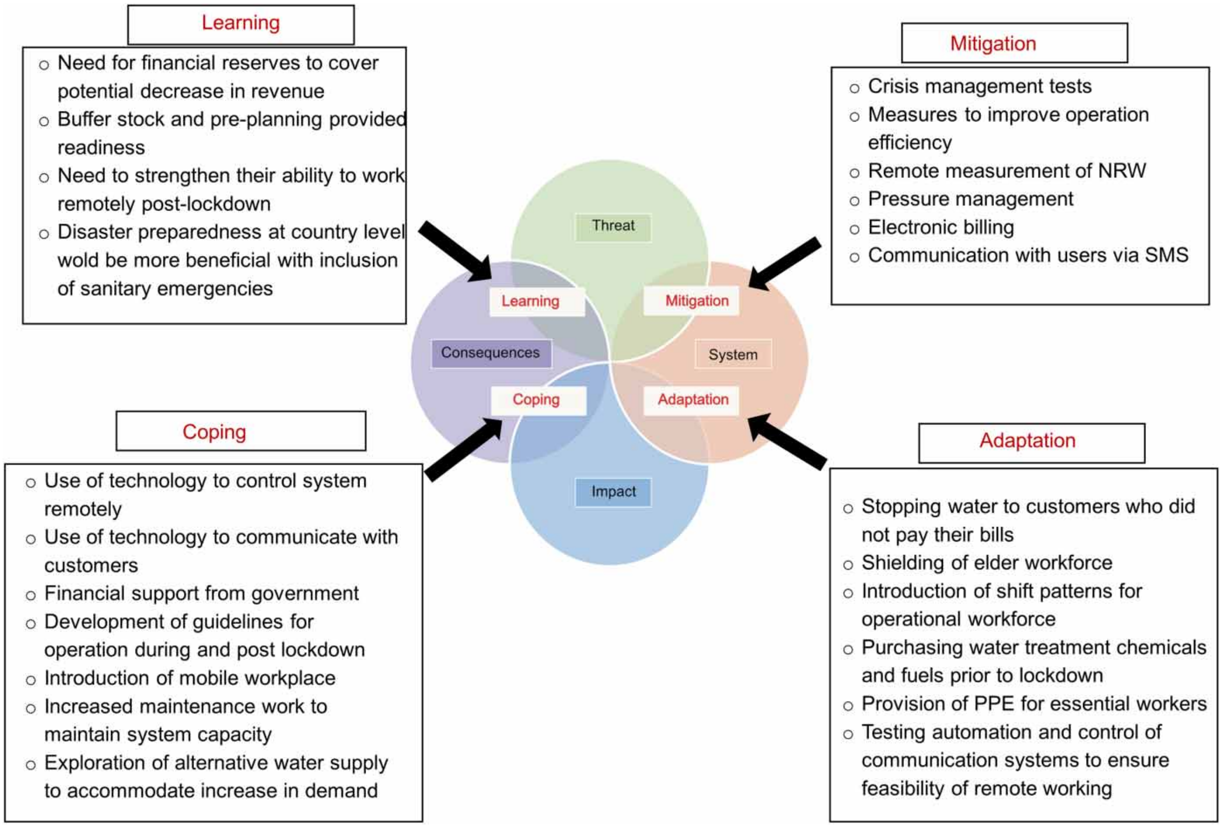

Figure 8 | Actions taken prior to and during the COVID-19 pandemic as mapped onto the Safe & SuRe framework.

Only four participants mentioned that COVID-19 has caused some changes in the intermittency of supply, while seven mentioned no changes, and the remaining participants were not sure. There were contrasting impacts observed in different settings. For example, in one case, electricity load shedding by other users resulted in the water company having access to electricity 24/7. This resulted in the company increasing supply hours from 4 to 6 hours per day to 12 hours per day. The increased supply of water resulted in customers, who were typically reluctant to pay their bills, to pay. In another case, due to an increase in electricity price during the peak season (summer) and a reduction in the water company's revenues, the intermittency of supply worsened.

Unanticipated challenges identified included three participants noting that consumers not paying their bills resulted in a reduction in revenue. Others observed increases in residential demand, in one case by 40%, and also changes in hourly consumption patterns. One other case noted an increase of 10% in system input, identifying more illegal connections as maintenance work continued during lockdown. Walton (2020) highlighted that, based on data from IBNet, the global average urban water use is typically 70% residential and 30% commercial, this split during COVID-19 is 82% residential and 18% commercial. This can be problematic as commercial users are more metered and are one of the main sources of revenue for utilities and in some places, they subsidise residential users. An increase in demand due to COVID-19 and a dry summer, along with having limited capacity to replace the elder workforce while they were shielding, pressure deficiency in urban water systems and in some cases water quality issues were also all noted as unanticipated challenges. The COVID-19 pandemic acted as a threat multiplier (Neal 2020), as interaction with weather events, or degree of intermittency in electricity in some cases, resulted in cascading failures. Water demand increases due to COVID-19 and a dry season, in combination with an increase in electricity prices, resulted in a reduction of duration of water supply. While in other cases reduced impacts and subsequent consequences improved the adaptability and coping level of the system, as a reduction in electricity demand resulted in an increase in the duration of water supply. Interventions or actions taken by water companies to reduce the impacts and consequences on the system are highlighted in Figure 8 and outlined below.

Intervention measures implemented

Mitigation measures, identified by participants, included crisis management tests and measures to improve operational efficiency and resilience. However, it was noted that the impact of COVID-19 surpassed any provisions that were made. This suggests that risk-based approaches are not that suitable during periods of high uncertainty. An increased use of technology was noted with the remote measurement of NRW and pressure management, and the utilisation of electronic billing and informing users via SMS.

Adaptation measures included the purchasing of water treatment chemicals prior to lockdown, with the testing of automation and control of communication systems carried out in order to ensure the feasibility of remote working. More elder members of the workforce were asked to shield, while shift patterns were introduced for the younger workforce. In some cases, two week shifts were introduced for the operation of critical assets such as water treatment plants.

Coping measures implemented resulted in the majority of water service providers continuing with production and supply of water. A few companies noted the use of technology to enable the remote control of systems. Remote contact also was used in contacting users for issuing bills by utilities in three of the countries. One participant from the development bank highlighted financial support that governments received to respond to the emergency as well as provision of guidelines for operation during and post the lockdown period. Other participants outlined measures that aided the ability to cope such as the introduction of a mobile work place to help keep staff safe, additional staff training and provision of personal protective equipment (PPE), and actively carrying out additional maintenance work in order to make use of the full system capacity. The introduction of a new mechanism to communicate with customers and the exploration of an alternative water supply to accommodate an increase in demand again contributed towards the system's ability to cope.

Participants identified many lessons that have so far been learnt during the COVID-19 pandemic. These include a need to build financial reserves to respond to any decrease in revenue and the creation of a buffer stock of operational and maintenance materials. It is, however, noted that to build resilience through the acquisition of such excess stock requires available finance to fund such measures.

Participants noted a belief in the ability to face a similar situation in the future and an emphasis on the view that disaster-preparedness should be done at the country level with the inclusion of sanitary emergencies. Finally, a need to create reserves and build better relations with suppliers so that materials can be received on demand, along with the design of better financial instruments to accelerate water utilities' strength and preparedness were also identified as lessons learnt.

Future operation

Barriers to change, identified by participants, include financial strains and a lack of e-infrastructure to facilitate activities such as automatic meter reading and electronic bill issuing. A number of participants also identified the resistance of the work force to adapt to new ways of working. However, a potential solution was proposed through an increase in internal communication and training.

Regarding the future operation of IWS, more digital utilities was suggested along with a perceived need for more risk assessments to be carried out, along with an increase in the need for preparedness.

It was suggested that a loss of income could force utilities to adapt to pre-paid metering, as a lack of income may result in poor operation. An increase in the maintenance and assessment of service was also suggested as a requirement to increase resilience, along with further exploration of alternative financial options. 50% of participants agreed that the COVID-19 pandemic will change investment priorities in resilience, while 23% suggested that it will not happen due to financial constraints.

The majority of the participants (70%) indicated that utilities will need support through this crisis and beyond. Suggestions on the types of support required differed and included:

- *National level*: Financial and human resources, strategic organisational guidelines, specific standards for planning and management of these systems as well as vulnerability assessments.
- *International level*: Financial support, practical examples on how utilities coped, creating awareness on the benefits of 24/7 supply and the need for a transition and how to do it.

There was a large emphasis on know-how and a suggestion that international collaboration should focus on producing more actionable knowledge resources. 50% of participants felt that research priorities will shift towards health-related issues, while others hoped that the pandemic will put more emphasis on water challenges and resilience of these systems. 50% of participants indicated that they would be interested in follow-up discussions.

CONCLUSIONS

This study provides an insight into the state of IWS systems in different local settings before and during COVID-19. It provides an understanding of organisational responses of water utilities to increased pressure under COVID-19. It should be mentioned that despite contacting several hundreds of potential participants via different social media, a limited number of responses were received. The incomplete survey responses indicated lack of data and information about these systems as all incomplete forms did not contain any quantitative information about the systems.

One third of the survey participants indicated that their water supply systems have 80–100% of the population on intermittent supply with the duration of supply ranging from 1 to 3 hours every 15 days to 19 hours per day. The volume and duration of supply are fixed in 50% of systems, while in the other 50% they are variable and unreliable. Infrastructure capacity and insufficient water resources were considered as the main causes of intermittency, while intermittent electricity was considered an external cause of intermittency in water supply in over 30% of systems. Changes in intermittent energy supply had cascading positive and negative impacts on IWS; improved energy supply led to improved water supply and revenue; reduced energy supply and revenue increased IWS, thus illustrating the fine line between a virtual and vicious water supply cycle.

Leakage and insufficient pressure were identified as main issues in operation of IWS systems, followed by infrastructure and water quality issues. Increasing treatment plant capacity, rehabilitation of mains, metering and pressure management were mentioned as some of the measures that are being implemented by 50% of the utilities, in order to facilitate transition towards continuous supply systems. Financial support and participatory decision-making were proposed as solutions to speed up the rate of implementation, to keep up with population growth (hence demand increase) and guarantee the success of transition plans.

The Safe & SuRe intervention framework was used to assess resilience of the IWS systems during COVID-19. Some participants indicated that a risk-based assessment of the system was carried out. Remote NRW measurement, pressure management, electronic billing and communications with users were mentioned among **mitigation measures** that were considered to improve operation efficiency, in preparation to respond to COVID-19 impacts. Some participants suggested that plans were adequate, however indicated that if the COVID-19 pandemic was prolonged, it would result in rising demand and a decline in revenue, hence it would not be sustainable in the long term. **Adaptation measures** included protection of the workforce through the introduction of shift patterns, shielding of elderly workforce and provision of PPE, purchasing water treatment chemicals and fuels, and testing automation capability in preparation for remote working. Participants reported financial support from government, introduction of mobile workforce, electronic communication with users, increased maintenance and the development of guidelines for operation during and post COVID-19 as **coping strategies**. **Lessons learnt** included increasing financial reserves and the ability to work and operate more remotely, greater international knowledge sharing and more practical examples of best practice for operation and management of systems during the COVID-19 pandemic, and support for the development of contingency plans for future threats.

This explanatory exercise indicated that utility challenges and participants' proposed solutions are very much in line with the five accelerators of the SDG6: optimised financing (financial reserves), improved data and information (remote operation and communication), capacity development (knowledge sharing and best practice guidelines to improve resilience), innovation (contingency planning) and governance (participatory decision-making). As COVID-19 continues to cause disruption to all aspects of life, it is hoped that it could act as an additional incentive to accelerate transition of IWS systems towards continuous supply.

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ETHICAL APPROVAL

Ethical approval was sought and received from the College of Engineering Maths and Physical Sciences (CEMPS) Research Ethics Committee, University of Exeter on 03/08/2020 (Ref: eEMPS000316 v4.0) and from IWA.

DATA AVAILABILITY STATEMENT

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

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