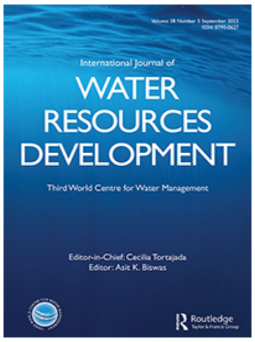

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Desalinated drinking-water provision in water-stressed regions: challenges of consumer-perception and environmental impact lessons from Antofagasta, Chile

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ABSTRACT
Desalination is increasingly popular for ensuring potable water. Using the City Blueprint Approach methodology in Antofagasta, Chile, we identify the barriers, opportunities and transferable lessons that can enhance governance capacity towards the successful implementation of desalination. Antofagasta's desalinization programme is associated with negative water-quality perceptions, environmental impacts and high energy demands. Additionally, the supply has a moderate impeding influence on water-use efficiency efforts. Consequently, we draft a priority ladder for water provision in water-scarce regions to: ensure access; reduce consumption; apply reuse; and explore renewable water resources – and if a combination of previous steps is insufficient, desalination may be applied to meet water supply shortages.

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Desalinization; water scarcity; consumer perception; water management; water conservation; Chile

Introduction

Freshwater security is a well-recognized priority for human health, the environment and the economy through Sustainable Development Goal (SDG) 6: Clean water and sanitation (Essex et al., 2020; Koop & Van Leeuwen, 2017; United Nations (UN), 2020). As a result of changing consumption patterns, increasing demand and water pollution, stresses exerted on the world's water resources as well as on cities' water supply and treatment are increasing (Dawoud & Al Mulla, 2012). By 2050, global freshwater demand is expected to increase by 20–30% above current levels (UNESCO, 2019). This increase is going to lead to more severe demand competition, resulting in an estimated 40% supply shortage by 2030 (McKinsey & Co., 2009). To maintain the habitability of urban regions, local authorities need to anticipate and adapt to increasing water stress and potential supply shortage (Ruth et al., 2007). Globally, 15,900 desalination plants are in operation which produce 95 million m^3/day of potable water. In particular, countries such as Saudi Arabia, the United Arab Emirates (UAE) and Kuwait largely depend on desalinated seawater. In addition, countries such as the United States, Egypt and Israel have large desalinization capacities (El Saliby et al., 2009; Zhu et al., 2019). The growing freshwater demand,

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technological improvements and reducing unit costs will likely contribute in an increasing number, capacity and efficiency of desalination practices in water-stressed coastal regions (Construvo et al., 2010; Dawoud & Al Mulla, 2012; Jones et al., 2019; Roberts et al., 2010).

As guidance for drinking water quality standards, desalination plants use the World Health Organization's (WHO) Guidelines for Drinking Water Quality (GDWQ) (WHO, 2011). These present the concentrations of a broad spectrum of contaminants, including inorganic and synthetic organic chemicals, disinfection by-products, microbial indicators, and radionuclides that ensure the safe provision of drinking water for consumers (Construvo et al., 2010). Beyond health-related aspects, aesthetic factors (or organoleptic parameters) such as taste, odour and turbidity, attributed to the presence of organic and inorganic contaminants and bacterial growth, are crucial in ensuring consumer satisfaction (Construvo et al., 2010; Shomar & Hawari, 2017). Furthermore, a positive attitude towards the public agencies and private companies regulating the sector are crucial for water service perception also when desalination plants are introduced (Haddad et al., 2018).

The process of desalinization is associated with negative environmental impacts due to discharges into the marine environment (Dawoud & Al Mulla, 2012; Lattemann & Hopner, 2008; Petersen et al., 2018; Von Medeazza, 2005). If desalination discharge, or brine, is released into poorly flushed environments, the salinity and temperature of the receiving waters increases substantially (Dawoud & Al Mulla, 2012; Qdais, 2008). Brine, which has a higher density than seawater, spreads over the sea floor in shallow coastal waters unless it is dissipated, affecting benthic organisms and seagrass beds. A thermal effect can in turn affect water quality processes and result in lower dissolved oxygen concentrations. Long-term exposure to unfavourable conditions can have a long-lasting impact on species composition (Dawoud & Al Mulla, 2012). Furthermore, a number of contaminants can be released during the construction and operation of desalinization plants. These include reaction (by-)products, from diverse processes such as construction, corrosion, pretreatment and cleaning (Dawoud & Al Mulla, 2012; Hoepner & Lattemann, 2003; Roberts et al., 2010). This presents the potential for acute and chronic toxicity (Construvo et al., 2010).

Desalination is also linked to significant energy demand (Østergaard et al., 2014). It has been estimated that a reverse osmosis plant requires between 0.5 and 4.0 kWh/m^3, which can vary depending on input salinity, temperature and the technology used (Goh et al., 2017; Li et al., 2018). This corresponds to about five times as much energy as traditional drinking water processes (Jacobsen, 2012).

As such, desalination faces three recurring challenges: (1) water quality perception issues; (2) environmental pollution of the residue of the desalinization process; and (3) decreased incentive to conserve water while energy demands of the process are high. The manner in which a city uses the available freshwater and how it adapts to increasing pressures on water as a scarce resource is greatly determined by the way that water is managed, and in turn how the sector is governed. Water management is about achieving goals in a practical and efficient way with the available means. Interlinkages between water quality, sanitation, infrastructure and environmental factors such as climate change can be essential. Water governance is about identifying, adhering and prioritizing values and converting these values into goals, targets and policies that water managers work with (Organisation for Economic Co-operation and Development (OECD), 2015). Across the globe, cities experience a shift from traditional public responsibility towards a diversification of governance modes where responsibilities are shared between different public and private actors across multiple governance levels (e.g. Lange et al., 2013; Mees, 2017). Beyond the ability of particular institutions, the joint capacity of different organizations involved to govern water challenges together is key and depends on a set of enabling conditions (Koop et al., 2017). Although today the efficient water use is recognized as being of high importance by many cities experiencing water scarcity, water governance is not always well embedded into efforts to adapt to the changing climate in dealing with water shortages and droughts.

Despite the valuable empirical work that links desalinization with water security governance (e.g. Baraua & Al Hosani, 2015; Fragkou & McEvoy, 2016; Gerlak et al., 2018; Gilmont, 2014; Molina & Melgarejo, 2016), social aspects are somewhat underrepresented. In particular, a more detailed place-based understanding of the capacity to govern water supply in water-stressed regions may be considered a valuable contribution. Here governance capacity can be understood as a set of key governance conditions that should be developed to address a common challenge (Koop et al., 2017). Accordingly, the aim of this research is to obtain a comprehensive, empirically based understanding of the critical points of improvements for the management and governance of drinking water supply in water-stressed regions and what the role of desalinization could be. In doing so, we assess the local capacity to manage and govern desalinized water provision in the case study of Antofagasta, Chile. This rapidly growing mining region is supplied by the largest desalinization plant in Latin America. The findings of this investigation therefore can reinforce our current understanding of the water supply challenges in Antofagasta, and assist decision-making processes in the efforts to mitigate water scarcity in water-stressed regions.

In what follows, the analytical framework and methodological approach are provided, including a case study description of Antofagasta. Next the assessment results are provided, followed by a discussion reflecting on the governance of desalinization worldwide based on key findings in the Antofagasta case study, and avenues for future research are offered. We end with the conclusions.

Analytical framework

To understand the key barriers for the provision of desalinized drinking water, we apply the City Blueprint Framework (CBF) in the region of Antofagasta, Chile. The framework consists of three complementary assessments:

- The Trends and Pressures Framework (TPF): 24 descriptive indicators about key social, environmental, financial and national governance aspects that may affect local water management.
- The City Blueprint Performance Framework (CBF): 24 performance-oriented indicators divided over seven broad categories: basic water services; water quality; wastewater treatment; water infrastructure; solid waste; climate adaptation; and plans and actions
- Governance Capacity Framework (GCF): 27 Likert indicators divided over nine governance conditions that together determine the capacity to govern water-related challenges (Table 1).

In order to assess key barriers and enablers for the governance of a secure drinking water supply, it is first necessary to understand the broader social, environmental and

Table 1. Water Governance Capacity Framework (GCF) (Koop et al., 2017).

Dimension	Condition	Indicator
Knowing	1. Awareness	1.1. Community knowledge
		1.2. Local sense of urgency
		1.3. Behavioural internalization
	2. Useful knowledge	2.1. Information availability
		2.2. Information transparency
		2.3. Knowledge cohesion
	3. Continuous learning	3.1. Smart monitoring
		3.2. Evaluation
		3.3. Cross-stakeholder learning
Wanting	4. Stakeholder engagement process	4.1. Stakeholder inclusiveness
		4.2. Protection of core values
		4.3. Progress and variety of options
	5. Management ambition	5.1. Ambitious and realistic goals
		5.2. Discourse embedding
		5.3. Management cohesion
	6. Agents of change	6.1. Entrepreneurial agents
		6.2. Collaborative agents
		6.3. Visionary agents
Enabling	7. Multilevel network potential	7.1. Room to manoeuvre
		7.2. Clear division of responsibilities
		7.3. Authority
	8. Financial viability	8.1. Affordability
		8.2. Consumer willingness-to-pay
		8.3. Financial continuation
	9. Implementing capacity	9.1. Policy instruments
		9.2. Statutory compliance
		9.3. Preparedness

Note: For more details regarding the rationale of the Trends and Pressures Framework (TPF) and City Blueprint Framework (CBF), see Koop and Van Leeuwen (2015), https://link.springer.com/article/10.1007/s11269-015-1139-z. For more details regarding the rationale of the GCF, see koop et al. (2017) https://link.springer.com/article/10.1007/s11269-017-1677-7.

financial context that may impede or enable good management practices (assessed by the TPF). Next, a broader assessment of water management across various domains provides a holistic overview for a better understanding of the barriers and enablers related to the regions water supply governance (assessed by the CBF). With this contextual understanding, the capacity to govern the drinking water supply in Antofagasta is assessed by the GCF to obtain an in-depth understanding of the key barriers and enablers of the critical points of improvements for the governance of drinking water supply in water-stressed regions and what the role of desalinization can be developed.

The primary reason for selecting this methodology is that it is able to provide a holistic overview of urban water management through a concrete, standardized and reproducible indicator assessment method. Its worldwide application in more than 75 cities and 40 countries allows for robust comparisons and the sharing of know-how between participating locations. The frameworks' indicators are concrete and standardized through a detailed description of the indicator's principal and scoring methodology that is applicable across cases (see Materials A–C in the supplemental data online). Reproducibility is ensured through full transparency of the information sources that are publicly available. For the GCF in particular (Table 1), a standardized indicator scoring procedure has been developed that consists of three steps. The first step provides a preliminary score based on a substantiation that includes publicly available information from policy documents, reports, media channels and the scientific literature. As a second step, representatives of key stakeholders are interviewed and this information is incorporated in the preliminary score substantiation. As a third step, the interviewees are asked to provide feedback on this substantiation. Based on these three steps a final score is determined.

Case study selection and data collection

In an effort to provide freshwater to a growing population and to support the economy's pivotal mining industries in a context of prolonged drought, the Chilean state has adopted a technologically oriented mitigation approach proposing the construction of desalination plants along its coastline (Fragkou & McEvoy, 2016). Particular attention has been given to the northern regions of the country, characterized by water-stressed climates and the predominance of water-intensive industries. The region of Antofagasta, and the region's homonymous capital city with a population of 439,000, is situated close to the coast (PopulationStat, 2020). Thus, the city of Antofagasta has been chosen as a representative case for this study for coastal water-stressed regions.

In 2003, the largest drinking water desalination plant in Latin America, the Planta Desaladora Norte (previously called La Chimba), was installed in Antofagasta with the goal of providing 100% of the city's drinking water. The plant currently produces 91.24 ML/day and supplies over 83% of the urban population (Barnett, 2020). Located within one of the driest regions in the world, this desalination plant has generated positive impacts for Antofagasta and provides a continuity of drinking water service for the citizens. However, there is mistrust for the direct consumption of water, primarily motivated by a strong communal memory of historically high arsenic contamination and organoleptic issues related to taste, colour and odour. Studies such as those of Fragkou and McEvoy (2016) indicate that 73% of citizens are not satisfied with the quality of the drinking water, and 82% believe that consuming water directly is harmful to their health, resulting in strong preference for bottled water. With regards environmental impact, there is insufficient consensus regarding the influence of the plant has on the marine biota – fishermen argue that marine life has decreased because of the desalination plant's activities (Barnett, 2020), while the plant operators argue that it has no impact on marine biota (Aguas Antofagasta, 2019). The plant has no independent energy source and is currently running on the central national energy system, which in turn is 63% based on fossil fuels (Agencia de Sostenibilidad Energetica, 2019).

In Chile, the national and regional governments mandate the normative and legislative contexts, but each municipality is responsible for the management of the water in its jurisdiction, in this case the Municipality of Antofagasta. The municipality has, like most in the country, a private subcontractor in charge of water supply (i.e. the Colombian firm Aguas Antofagasta) and collection of wastewater (the Chilean private–public company ECONSSA [Concessionaire of Sanitary Services of Antofagasta]). All relevant actors of the water sector are summarized in Table 2. The stakeholders with high influence and the most interest (key players) were identified as ECONSSA, Aguas Antofagasta, the Municipality of Antofagasta, the General Directorate of Water (DGA) of the Ministry of Public Works and the CREO (Private-Public Organization for Dialogue). The stakeholders with a high interest but low influence (subjects) are neighbouring communities, the University of Antofagasta, the Catholic University of the North and other scientific communities.

Table 2. Relevant actors (including stakeholders, community groups and responsible authorities) of Antofagasta water governance system.

Governance level	Urban water governance stakeholder	Societal layer	Role in Antofagasta's water governance system
Supranational	Empresas Públicas de Medellín (EP)	Market	Colombian company dedicated to the water and electricity sector. Currently owner of Aguas Antofagasta
National	Ministry of Public Works (Ministerio de Obras Publicas – MOP)	State	Department working in the General State Administration responsible for the provision and administration of infrastructural works and connectivity, public buildings and optimal use of water resources. Within this, the Superintendence of Sanitary Services and General Directorate of Water
	General Direectorate of Water (Direccion General del Agua – DGA)	State	State-owned company of the government of Chile responsible for planning and managing the region's water cycle. They revise and release permits for all water distribution schemes
	Superintendence of Sanitary Services (SISS)	State	Public institution responsible for ensuring sanitary sector operational compliance and water quality of drinking water
	ECONSSA	State/market	Semi-state company that overlooks concession contracts between sanitary companies and the state. Contracted by the city council:responsible for the collection, treatment and disposal of wastewater
Regional	Antofagasta Regional Government (GORE Antofagasta)	State	Public institution that provides direct services to citizens and provides technical, economic and technological support to the municipalities
Municipal	Municipality of Antofagasta	State	Local governing body responsible overall for the management and supply of freshwater in the city
	Aguas Antofagasta	Market	Private company responsible for the supply of drinking water to the city of Antofagasta
	Neighbourhood Communities	Civil Society	Citizen organizations aiming to serve as a platform of local organization and communication between civil society and authorities
	Catholic University of the North (Universidad Catolica del Norte – UCN)	Scientific community	Private Catholic University located in Antofagasta. Eighth oldest university in Chile. Within this CEITSAZA – Catholic North University; investigation centre of water Innovation and technology
	University of Antofagasta	Scientific community	Public University located in Antofagasta. Within this is CREA – University of Antofagasta's Regional Centre for Environmental Studies and Education
	CREO Antofagasta	Scientific community/ market	Public/private initiative alliance funded predominantly by the mining sector that aims to project and facilitate a sustainable urban development of Antofagasta for 2035

Table 3. Number of interviewees per stakeholder organization.

Organization	Interviewees
Aguas Antofagasta (AA)	5
Ministry of Public Works (MOP)	2
National government – Regional Deputy	1
Superintendence of Sanitary Services	1
CREO	1
CREA – University of Antofagasta	1
CEITSAZA – Catholic North University	1
University of Antofagasta	1
ECONSSA	1
Municipality of Antofagasta	3
Mining Company Lomas Valles	1
Neighbourhood Organization Central Area	1
Neighbourhood Organization Las Rocas	1
Total	20

Data collection was done in two principal manners: desk research and on-site data collection. In March–June 2019, information was obtained from scientific articles, reports and policy documents, from which a preliminary scoring of each indicator was made. The TPF and CBF (see materials A and B in the supplemental data online) include merely quantitative scores that were mainly scored through desk research, and interviewees either verified or provided additional information to improve the accuracy of the scores. Although the GCF relied on policy analysis and literature, more emphasis was put on the perspectives of the interviewees. A total of 20 interviews (Table 3) were conducted in June–July 2019. These interviews were face-to-face semi-structured and lasted about one hour. The predefined questions (see Material C in the supplemental data online) and the interviewee area of expertise, role and responsibility formed the starting points of tailored questions to adequately score the indicators. Professionals with different backgrounds and responsibilities were selected to reduce the risk of bias. A coding system is applied in this paper to consistently refer to these anonymized interviews.

Results

In the results we first discuss the TPF and CBF key findings in order to obtain a holistic understanding of the current status of urban water management in Antofagasta. Next, the GCF provides a more in-depth analysis of how well stakeholders and authorities are able to govern the challenges related to the provision of desalinized water in the water-scarce region of Antofagasta.

Trends and Pressures Framework (TPF)

A total of 24 descriptive indicators within the social, environmental, financial and national governance categories are used in the TPF to evaluate the context that Antofagasta faces (Figure 1). The key indicators of concern for Antofagasta are heat risk, education rate, water scarcity and water quality. Heat risk is of great concern because the combined number of tropical nights and hot days in a year is more than 77 (Villarroel & Paola, 2013) and the city has a green/blue urban area percentage of only 0.003%. Education rate is evaluated as a concern based on a primary education rate of 93% (World Bank, 2013). The

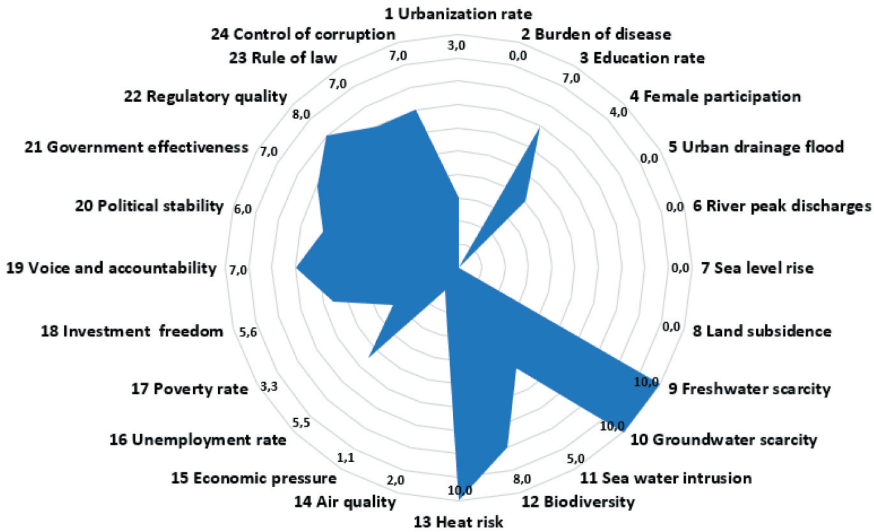

Figure 1. Trends and pressures framework results of the city of Antofagasta, Chile. The principal message is the bluer the better. Indicators score between 0 (low) and 10 (high). This holistic water management assessment shows that, amongst others, freshwater scarcity, groundwater scarcity and biodiversity are limiting conditions. For more information on the calculation of this framework, see Material A in the supplemental data online.

indicator water scarcity, also evaluated a concern, shows that 99% of total renewable freshwater resources (consisting of both groundwater and surface water) are abstracted in the region. Furthermore, it is calculated that the abstracted groundwater represents 391% of the annual groundwater recharge of the region (DGA & World Bank, 2013). These numbers indicate that the vast majority of surface waters is depleted, and groundwater reservoirs are decreasing drastically. Water quality is also considered a concern, as 59% of the region's waters are considered to have less than good ecological status (EPI, 2010). The factors concerning political instability, unemployment rate and inflation rate have been scored as a medium concern, while the burden of disease and economic pressures are a low concern. It is worth mentioning that although there are currently no concerns with respect to political instability and economic pressures, recent social uprising in the country can influence these indicators in the near future.

City Blueprint Framework (CBF)

The City Blueprint Performance of Antofagasta shows important strengths and weaknesses of the city's water resources management. Access to drinking water and sanitation (indicators 1–3) score highly. The operation cost recovery (indicator 14) is high, indicating a sustainable financing of water services. Drinking water consumption (indicator 23) is relatively low and thus scores highly. The lowest scoring indicators relate to the treatment of wastewater and solid waste (indicator 5, 7–10, 16 and 17) leading to environmental pollution. Because stormwater is not separated (indicator 11), it cannot be used for non-potable purposes. Notably, water system leakages are over 30% (indicator 13), leading to the spilling of not only water but also the energy necessary for the desalinization process.

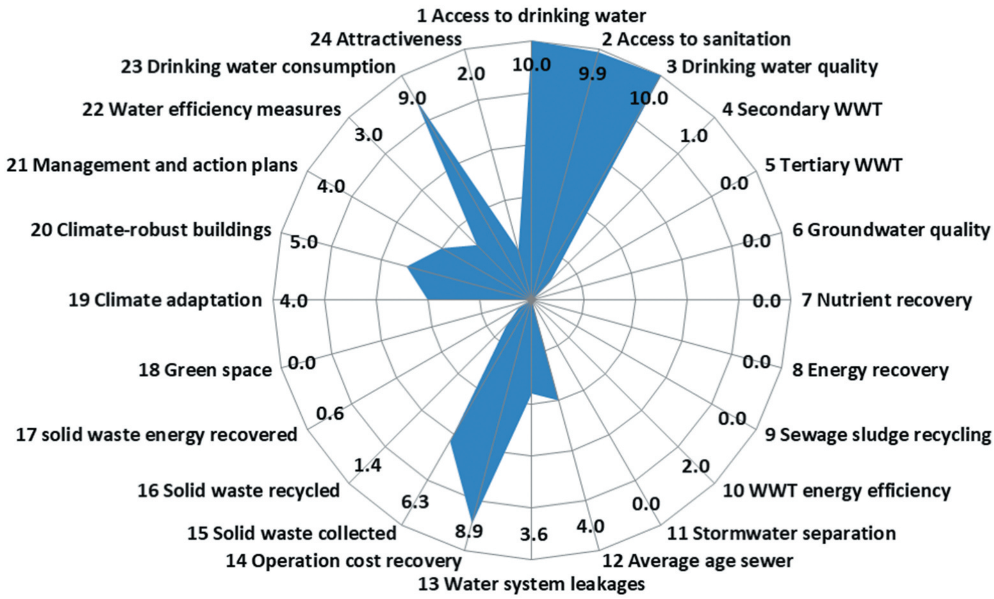

Figure 2. City blueprint framework results of the city of Antofagasta. The principal message is the bluer the better. Indicators score between 0 (low) and 10 (high). This holistic water management assessment shows that, amongst others, wastewater treatment and water system leakages perform poorly. For more information on the calculation of this framework, see Material B in the supplemental data online.

Figure 2 shows that environmental pollution (indicators 4–6 and 15–17) and spilling of water and energy (indicators 8, 9, 13, 16 and 22) are high in Antofagasta. Interestingly, the drinking water quality (number of samples complying with local standards; indicator 3) is high. Water quality perception issues are therefore likely to be more related to organoleptic parameters (colour, smell, taste and turbidity).

Governance Capacity Framework (GCF)

Figures 3 and 4 summarize Antofagasta's current governance capacity to address water scarcity. Overall, water scarcity and the steep increase in water demand as well as the environmental impact of desalinization are generally not perceived as urgent and little effort has been made to promote ecological conservation (indicators 1.2 and 1.3). The window of opportunity for entrepreneurial agents (indicator 6.1) to innovate is limited. Furthermore, the division of responsibilities, management fragmentation and poor evaluation of existing policy and management practices are important points for improvements (e.g. indicators 2.3, 5.3, 6.1 and 7.2). On the other hand, existing goals, such as a regional centralized desalinated-water distribution network, are both ambitious and realistic (indicator 5.1) and there is a strong consensus that adaptation is crucial for the development of the region (indicator 5.2). The nine governance conditions shown in Figure 3 are the average of three indicator scores, which are substantiated in detail below.

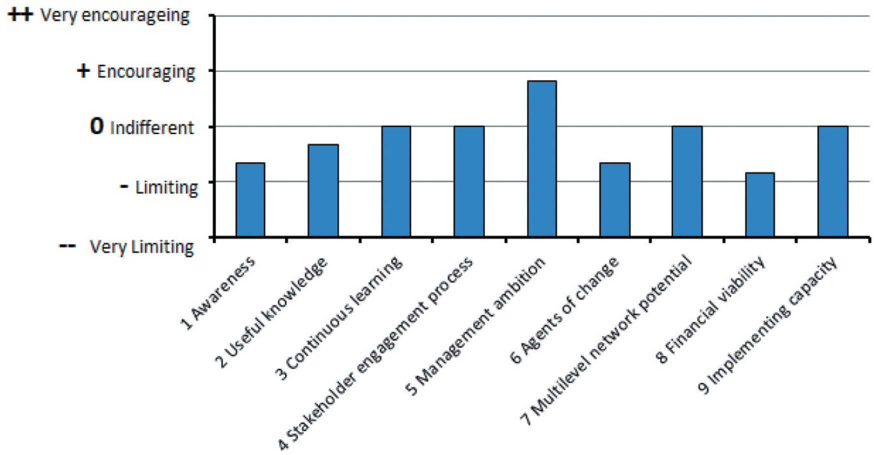

Figure 3. Governance capacity of Antofagasta, by each condition. Each condition is the average of the corresponding three indicators, as shown in Table 1 and Figure 4. The Likert scoring ranges from very encouraging (++) to very limiting (–) to the overall capacity of stakeholders to govern secure drinking water in the water-stressed region. For more information on the calculation of this framework, see Material C in the supplemental data online.

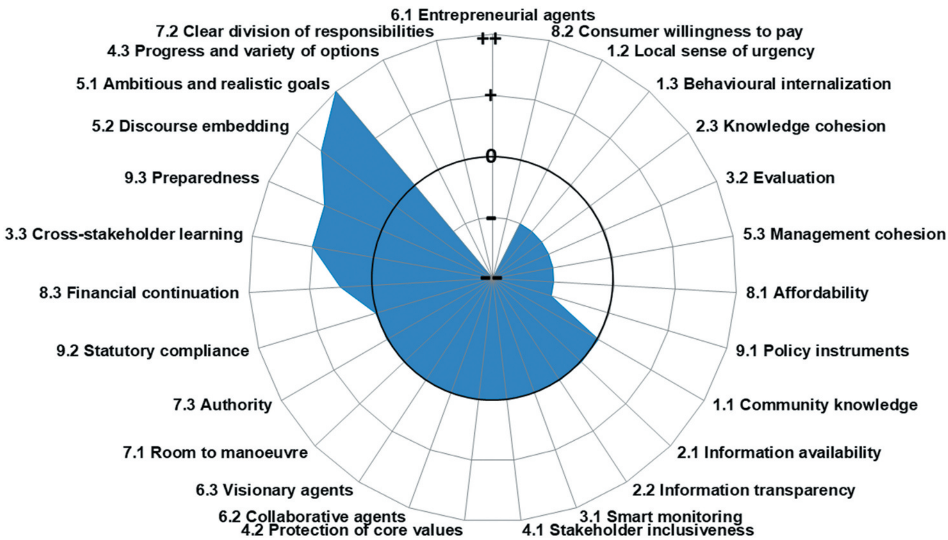

Figure 4. Capacity of Antofagasta to govern its desalinized drinking water supply. The 27 indicators are ranked clockwise from most limiting (–) to most encouraging (++) as regards overall governance capacity.

Condition 1: Awareness

The region of Antofagasta has a history of extremely dry conditions (NE004, NE006, NE007, NE009, NE013 and NE01), yet citizen knowledge regarding the long-term water stress implications or possible preventative actions is low (indicator 1.1: NE003, NE004, NE010, NE014, NE015 and NE017). There is distrust of the quality of tap water due to the collective memory of historic levels of contaminants (e.g., arsenic) (NE002 and NE005) (Aguas Antofagasta, n.d.), which extends to mistrust and misinformation regarding the current quality of desalinated water (NE003). The water supply security provided by the plant diminishes perception of water scarcity or water conservation as relevant issues (indicator 2.2: NE002, NE013, NE015 and NE017). Furthermore, there is little awareness amongst local stakeholders about the resources that go into desalination, or its impacts on the ecosystem (NE002, NE004, NE008 and NE015), and consequently no sense of urgency regarding environmental degradation (NE013). There is little or no effort to reduce water use at the household level (indicator 1.3: NE002, NE009 and NE015), resulting in an average domestic water consumption of 180 litres/person/day (NE003, NE005 and NE009). Only a minority of citizens, some independent initiatives and the public sector seek promotion of sustainable practices (NE002, NE005 and NE015).

Condition 2: Useful knowledge

Useful knowledge evaluates the comprehensibility of available information for interpretation and analysis. Comprehensible information about the water utility's (i.e. Aguas Antofagasta's) activities are shared on social media (NE003, NE007, NE008, NE011, NE014, NE017 and NE019). Accurate technical information for water production, treatment and operation of the desalination plant is available (NE017) and national studies such as water scenarios (Escenarios Hídricos) by the Foundation Chile (Fundación Chile) provide decent and reliable knowledge (NE006, NE009, NE012 and NE015). Information is limited with respect to a holistic understanding of the available water resources, their utilization and ecological conditions (indicator 2.1: NE004, NE014 and NE017). For example, as a result of insufficient capacity of the DGA, auditing and documentation of water rights and their exploitation are weak and often not up to date (NE019). Existing information regarding the region's water resources and their use is accessible (indicator 2.2: NE010, NE014 and NE017), mostly online, and often not easily comprehensible to non-experts (NE002, NE003, NE006, NE007, NE009, NE011 and NE015), which results in an inequality of access to knowledge (NE019). A simple example is that of the units of the data published; water permits production volumes are given in L/s, yet volume charged to consumers is given in m^3, making it difficult to visualize or relate (NE003).

Condition 3: Continuous learning

Continuous learning is key for adapting to evolving situations and uncertainties. Monitoring capacity (indicator 3.1) is particularly limited and outdated within the public sphere (NE002 and NE016), attributed to scarce resources. The regional DGA currently employs only four people responsible for monitoring over 200 locations over 126,050 km^2 (NE005) (BCN, n.d.). Consequently, efforts focus on water rights use auditing, with little capacity left for further data analysis. The private sector has higher capacity for monitoring internal processes (NE002 and NE016). Evaluation of policy and implementation (indicator 3.2) is also inflexible within the public sector, while the private is seen to adapt faster. At a national level, the revision of norms within the public administration is a lengthy process, taking over five years (NE003, NE006, NE008 and NE009). The legal base for water management, the Water Code adopted in 1981, was modified in 2005 after 13 years of discussion. It allows for private ownership of water rights as well as their free transferring – a framework under constant dispute, receiving opposition from those who believe the resource should be safeguarded by the state. This division of opinion plays an important role in the discontinuity of evolving norms (NE016). Furthermore, large-scale desalination is a new phenomenon that is not treated appropriately by the law, in aspects of operation as well as the treatment of discharge waters (NE013). Water quality parameters such as boron and the Langelier Index and regulation of discharge are absent (NE09 and NE013). Cross-stakeholder learning (indicator 3.3) is a positive indicator, since strong efforts for discussion between sectors can be observed at the local level (NE006, NE013, NE014 and NE016). Collaborations between local universities, the municipality, CREO, Aguas Antofagasta, the Superintendent of Sanitary Services, the Ministry of Public Works and the DGA have resulted in numerous educational programmes, seminars, worktables and training sessions with the aim to improve public knowledge, share expertise and target particular issues (NE002, NE008, NE012–NE014, NE016 and NE017).

Condition 4: Stakeholder engagement process

Communication between Aguas Antofagasta and citizens is adequate with respect to the quality and continuity of the water supply, having improved information availability and consultation channels (e.g. WhatsApp, Twitter and an emergency number) in recent years (NE010, NE016 and NE019). However, the level of stakeholder participation in the decision-making process (indicator 4.1) is low, mostly informative or consultative, untimely with little binding (NE004, NE006, NE008, NE011, NE014 and NE019). There is a strong centralization within both the public and the private sectors (NE005, NE006, NE014–NE017 and NE019). The indicator protection of core values (indicator 4.2) evaluates the confidence that stakeholders feel with regards their core values being respected. With regards the sanitary sector, namely the health and wellbeing of citizens, some question the capacity of the law to ensure access to water; the historic privatization of the resource has resulted in water being traded on the free market, with powerful entities being able to purchase abundant water permits. In a region where water resources are so scarce, this is believed to be an important root of power and wealth imbalance. Particularly in rural areas, conflicts arise due to the discordance between commercial interests of the productive sector and those of indigenous communities who require water for basic needs (NE004 and NE005). Thus, it can be perceived that the system of private ownership of water rights, while aiming to optimize the resource's use, is unable to fully protect the values of local communities and the needs of those with limited economic resources (NE011). Procedures within the water sector, such as water permit applications and maritime concessions, are clear with standardized guidelines, but lengthy, unintuitive and inflexible (NE003, NE009, NE012, NE013 and NE019).

Condition 5: Ambitious and realistic goals

The goals of the water sector of Antofagasta are considered very ambitious and realistic (indicator 5.1). With unique initiatives such as The Antofagasta Recycled Water System (SARA) by CREO, the city is developing the treatment and reuse of municipal wastewater for green public areas (NE012, NE013 and NE019). Another ambitious and realistic idea yet being developed is a centralized regional interconnected water network of pipelines (similar to an electricity grid), where fresh water from the mountains as well as desalinated water can be distributed across the region (NE003, NE004, NE006, NE011, NE017 and NE018). However, it is important to mention that particularly neighbourhood communities feel that the sanitary service still fails to meet basic expectations (NE008), and ambitions are out of sync with the reality of mistrust in tap water (NE011). The indicator discourse embedding (indicator 5.2) evaluates whether management ambitions match dominant values and principles. This indicator is evaluated low since the political and normative spheres do not reflect the need for particular legislation for the northern regions of the country. Only in 2005 was the national water quality law NCh 409 modified to restrict arsenic concentrations to 0.01 ppm, despite the previously high values (Aguas Antofagasta, n.d.). In line with the above, management cohesion (indicator 5.3) is also scored as a limiting indicator. The Water Code, environmental system and primary norms are centralized, the same across the whole country, and do not consider the significant regional differences in geographical characteristics, technical capacities and financial resources (NE003–NE006, NE013, NE016, NE018 and NE019). A regional application of norms is lacking.

Condition 6: Agents of change

Agents of change refers to the motivation of people in any position (of power or non-power) and the support given to their efforts to change currents approaches. Our results depict that there are numerous opportunities for funding and support for both public and private initiatives of entrepreneurial activities (indicator 6.1: NE004, NE006 and NE015). The water utility Aguas Antofagasta offers problem-solving programmes for university students (NE003). The Espacio Atacama local co-work, run by the My North Foundation (Fundacion Mi Norte), offers an 'incubator' system for small and medium-sized enterprises (NE006). The municipality offers community development programmes to guide incentives (NE012). The National Fund for Regional Development (CORFO) offers financial support for entrepreneurial incentives. Despite all the above, practically no entrepreneurial activity is present within the water sector (NE003, NE007, NE017 and NE019). The only active initiative known is Aquaservax (supported by Antofaemprende), which offers consumption-reduction devices for domestic use (NE019). As a cause, some perceive the opportunities as weak, short term or lacking technical support (NE006, NE014 and NE019). Others mention normative barriers or economies of scale as barrier for smaller businesses (NE017). The extent to which stakeholders are able to build trust-collaborations and connect business (indicator 6.2) is scored as indifferent. Worktables and committees conducted between diverse actors provide frequent opportunities for interaction (NE013 and NE014) and there is adequate trust and disposition for collaboration between the main stakeholders (NE004 and NE016). An example is the incentive CREO, which aims to construct participatory long-term strategic city planning (NE016). Nonetheless, some identify a lack of a common goal for the actors of the water sector (NE004). Finally, the extent to which actors are able to effectively push forwards long-term strategies (indicator 6.3) is also scored indifferent. Within the public sector the Superintendent of Sanitary Services formulates 'development plans' with outlook for 15 years and the first five years being binding (NE016). The DGA develops the Strategic Plan for the Management of Hydraulic Resources (NE012). However, the projections of these efforts are perceived as insufficient considering the complexity of the local environment (NE010). There is a sense of regional resentment towards the central government, a feeling that the region's resources are being exploited for short-term national economic wealth (NE010 and NE012). A long-term unified strategy or vision for sustainable water management does not exist (NE004 and NE010), and overall application of strategic planning is sectorial and fragmented (NE016).

Condition 7: Multilevel network potential

Room to manoeuvre (indicator 7.1), which evaluates the opportunity that actors have to explore different alternative pathways, is scored as indifferent. This is due to inflexible national norms and long-lasting procedures for obtaining permits limit the possibilities for action (NE003 and NE007), particularly for the drinking water provision and sanitary sector (NE004). For example, a new law (10.795-33) currently in the Senate seeks to discourage sanitary services from performing non-regulated services, such as selling treated water for recycling (NE004). The division of responsibilities (indicator 7.2) is also considered a limitation. Studies by Akhmouch (2012) and the DGA and World Bank (2013) highlight that Chile has one of the highest levels of fragmentation of responsibilities when it comes to water-related competences, with over 40 authorities involved in the sector (NE019). Mapping these, it can be observed that there are areas of overlap as well as gaps (NE004, NE005) (OECD, 2015). The basic responsibilities of the sanitary sector are clearly and strictly formulated (NE003, NE006, NE012 and NE019) between the water utility Aguas and ECONSSA (SEMBCORP) (NE002, NE013, NE010 and NE016). This separation is a reflection of the historic separation of concessions in the sanitary service, and results in a dilution of long-term responsibilities between the two companies (NE016). Public administrations, namely the Superintendent of Sanitary Services, DGA and the municipality monitor compliance, assign permits and manage aspects of urbanistic planning respectively (NE003, NE005, NE017 and NE009). These institutions, however, can have uncoordinated or overlapping incentives that lead to inefficient allocation of funds (NE006 and NE017). It is identified that the legitimate forms of power and authority are rather restricted to addressing the sustainable production and use of desalinized drinking water (indicator 7.3: NE006 and NE019) (DGA & World Bank, 2013).

Condition 8: Financial viability

Affordability for basic water services is limited (indicator 8.1). Full coverage of sanitary service is available to Aguas Atofagasta's operational area (NE007, NE011, NE013 and NE016); however, large outskirts of the city, mostly composed of immigrant neighbourhoods, are not connected (NE006, NE008, NE009, NE011 and NE017). Furthermore, Antofagasta has one of the most expensive tap water tariffs in the country (NE003, NE005, NE011, NE013, NE015 and NE016). Antofagasta's inhabitants pay 1500 pesos/m^3 for the water service (Aguas Antofagasta, 2018), which can triple during the summer period, as a result of the gradual increase in the tap water tariff during the period December–March for households that consume over a calculated average of the population. Climate adaptation measures, such as water collectors or filters, are scarce and not accessible (NE008). The state has responded to this by implementing subsidies for the most vulnerable families (NE007 and NE014). It must be noted that the price of tap water is calculated based on a 'model' company that does not consider the costs of desalination (NE003 and NE004). Consumer willingness to pay (indicator 8.2) is rather low. There is a lack of understanding and mistrust in the calculation of the tariffs and generally resentment towards the sanitary sector, mostly based on the historic levels of contamination of arsenic, service interruptions and bad odours during the implementation of the desalination plant. As a result, citizens would not be willing to pay more (NE004, NE008, NE011 and NE015). The consumer has high expectations of tap water, but limited understanding of what the service entails or what their responsibilities are (NE004 and NE015). Finally, financial continuation (indicator 8.3) is considered indifferent. Private companies, particularly Aguas Antofagasta and mining companies, have stable financial resources for innovation (NE004, NE007, NE017 and NE019). However, due to the private actor's diverse objectives their financial allocation can be fragmented (NE016). Furthermore, some perceive that decisions can be made to benefit investors or investments can be postponed unless absolutely crucial (NE019). This can be evidenced by the low reposition rate of the pipeline network of 0.6%/year (NE019), suggesting that the pipeline system as a whole is repositioned after 167 years. Basic activities of the DGA, such as flow measurement, involve constant and predictable costs and are performed continuously (NE005). The public administration, however, has insufficient and discontinuous funds for improving infrastructure, maintenance, follow up of projects or overall innovation (NE006, NE012, NE014, NE016–NE019) (DGA & World Bank, 2013).

Condition 9: Implementing capacity

Policy instruments (indicator 9.1) are used scarcely to stimulate desired behaviour. At a citizen level the only policy instrument used is a gradual increase in the tap water tariff during the period December–March for households that consume over a calculated average of the population (NE003, NE005 and NE006). There is disagreement on whether this is successful; some claim it pushes for a reduction in consumption (NE013) and others believe it is unrealistic and harmful, as citizens' consumption is by need higher in summer (NE008). Municipal subsidies for water bills for the most vulnerable families are an important and helpful instrument (NE003, NE005 and NE008). At a commercial and industrial level there are no particular norms to stimulate efficient use of the resource (NE013, NE016 and NE019), which can be seen in the pipeline network leakages of 32% (NE019). Furthermore, a penalty for not using one's water rights (and even the risk of losing it) aims to encourage the optimal economic use of water resources (Bravo & Blanco, 2014). With regards statutory compliance (indicator 9.2), existing legislation is complied with (NE002, NE004 and NE017). Particularly the water utility Aguas Antofagsta and the industrial sector are perceived to have high compliance with regards water quality, as a result of the firm's monitoring of Superintendent of Sanitary Services (NE002–NE004, NE007, NE009 and NE013) – observing a compliance level of 99.4% with national drinking water quality criteria. Yet, some legislation is still weak or unclear, for example, with regards the treatment and deposition of residual water, in which compliance is still poor (NE007, NE013 and NE017). Finally, the level of preparedness for gradual or sudden events (indicator 9.3) is evaluated as positive, mostly attributed to the well-coordinated division of roles for scenarios of emergencies, resulting from the vast experience that Chile has with natural disasters (NE005 and NE006). Some vulnerabilities remain nevertheless. Antofagasta is very vulnerable to precipitation as there is no infrastructure for rainwater drainage, and recently rain events have been occurring more frequently (NE002, NE003, NE005 and NE014). The city is one of the only in the country that operates a dual-provision system (desalinated and continental water) that can complement or substitute each other (NE003, NE005, NE007 and NE012). In case of failure of both, in theory the city has existing reservoirs that enable continued water provision for 36 hours. However, this back-up water reservoir is not always full or readily available (NE009). The desalination plant itself faces a major challenge of securing energy independence, as currently it is entirely dependent on the national system (NE013) and chlorine storage as it is dependent on weekly importation (NE009). Expanding the operational area of the sanitary system, renovating pipelines, reducing air/water contamination, creating contingency plans and regional water interconnection are perceived as the next challenges to tackle (NE004, NE010, NE012 and NE014).

Discussion

The principal barriers identified for the effective implementation and governance of a desalinated water system are the perception and trust of consumers, a lack of awareness and action in response to environmental impacts, and the water–energy nexus. The recent literature and opportunities for these challenges are discussed below.

Perception and trust

Antofagasta has a very high compliance with national drinking water quality criteria regarding chemicals and metals, turbidity, presence of microorganisms and organoleptic parameters (colour, smell, taste and turbidity) (SISS, 2019). With regards chemicals and metals, national legislation is predominantly in line with international guideline of the WHO on safe drinking water quality (WHO, 2017). With regards turbidity, total dissolved solids (TDS) and organoleptic parameters, however, significant differences are found between the Chilean legislation and the WHO's recommendations. For example, the WHO states that a TDS concentration > 1000 mg/l become significantly unbearable to consumers, while at present the Chilean norm allows for up to 1500 mg/l. The recommendation for turbidity is < 0.1 nephelometric turbidity units (NTU), however the national limit is 2.0 NTU. The recommendation for sulphates (which cause odour) is 250 mg/l, and the national limit is 500 mg/l. Thus, despite meeting the criteria to ensure a healthy drinking water supply, organoleptic parameters exceed international standards of taste, colour and odour – which in part can explain the strong citizen rejection. Until the 1990s, health-related quality parameters were widely accepted as the sole indicator of drinking water standards. However, today the public plays an increasingly important role in determining acceptable levels of drinking water properties and safety (Miguel De Franca, 2010). Water organoleptic parameters, particularly taste, are paramount for quality perception, service satisfaction, willingness to pay and the selection of water sources, including desalinized water (Gorden, 2000; Miguel De Franca, 2010). The importance of these parameters should not be underestimated on the basis of lacking health implications. Water testing must include measurements of physicochemical properties, biofilm presence and organoleptic parameters (Shomar & Hawari, 2017). Furthermore, qualitative research on water organoleptics suggests that people prefer what they are used to, and frequent changes in quality, such as the gradual expansion of the desalinated supply throughout Antofagasta, are inversely associated with quality acceptability and water risk judgements (Syme & Williams, 1993). Foreseeable changes in organoleptic parameters, for instance, owing to upgrades in the water distribution or treatment system, must be anticipated and communicated.

In addition to organoleptic parameters, consumer perception of water quality and acceptance results from a complex interaction of numerous additional factors. These include trust in water suppliers and regulators, risk perception, attitudes towards water chemicals, prior experience and information reception (Baker, 1998; Johnson, 2003;

Miguel De Franca, 2010; Nancarrow et al., 2010). Trust in companies, organizations or governmental institutions is linked to the perception of water quality and risk, and thus acceptability (Johnson, 2003; Poortinga & Pidgeon, 2003), although the causal order of this relationship is not clear (Bratanova et al., 2013; Miguel De Franca, 2010; Syme & Williams, 1993). A lack of trust in water companies motivated by the scepticism that these actors are motivated principally by their financial benefits, as is observed in Antofagasta, is a common phenomenon (Miguel De Franca, 2010). Factors that can improve the relationship are perceptions of care, value similarity, competence, integrity, cooperation and openness, and a sense of fairness and equitability within the water provision system (Nancarrow et al., 2010). Particularly a large portion of consumers express that the presence of chemical pollutants in drinking water is a principal concern (Miguel De Franca, 2010). A higher perception of risk has also been related to the perception of prior negative outcomes resulting from the system (Nancarrow et al., 2010). These experiences can provide the basis for the interpretation of new information and can have a strong effect on perceptions of water quality and acceptability (Miguel De Franca, 2010). The collective memory of arsenic contamination of drinking water in Antofagasta, and the significant health impacts this had on the population, is thus a key factor in understanding consumer mistrust and behaviour in this region.

It is widely considered that coherent and accessible information must be available to all citizens. Nonetheless some argue that the effect of scientific and technical information alone on public perception can be limited (Miguel De Franca, 2010). A statistical experiment by Johnson (2003) on 494 residents of New Jersey found that reading water-quality reports did not shift customers' evaluations of water quality and utility performance from the evaluations of those in the control group, who did not see a report. The recommendation is not against the provision of such reports, but it rather highlights the challenge of effective communication, the limitations of scientific reporting and the need to complement information channels. For example, interpersonal sources of information, consisting of family members and friends are believed to also have a strong influence on perceptions, often overlooked in the drinking water context (Park et al., 2001). Thus, as a transferable lesson, education at the school, community and other levels aiming to promote understanding of drinking water issues should be transversal across generations (Miguel De Franca, 2010).

Environmental impact

Technological advances have resulted in the development of new and efficient desalination processes; however, the costly handling of brine, a hypersaline concentrate discharge associated with negative environmental impacts (Jones et al., 2019), remains a principal challenge. Major concerns are related to the ecological effects associated with the physiochemical alterations to receiving environments and the contamination with toxic chemicals around brine discharge locations which pose risks to local ecosystems. On average, for every 1 m^3 of desalinated water, 1.5 m^3 of reject brine is produced as by-product (Jones et al., 2019).

Traditionally a limited number of discharge methods has been used to dispose of brine, including deep well injection, land disposal evaporation ponds and mechanical/thermal evaporation (Afrasiabi & Shahbazali, 2011; Dawoud & Al Mulla, 2012; Jones et al., 2019). Nonetheless, these methods are associated with considerable practical and economical challenges (Dawoud & Al Mulla, 2012). Subsequently, in coastal areas the most common method is direct discharge into the ocean (Purnama et al., 2003), as is the case in Antofagasta. A principal factor of consideration to reduce the extent of this ecological impact is the location of the discharge site (Roberts et al., 2010). Dispersion is believed to occur faster in deeper waters where currents tend to be stronger (Purnama et al., 2003). Subsequently, exposed, open seas are desired for discharge locations (Roberts et al., 2010). Dilution can be further enhanced by the release of brine through multiport, submerged pressure-driven diffusers (Ahmad & Baddour, 2014). Lastly, a simple method to reduce brine salinity is mixing brine with alternative water sources of a lower salinity, such as treated wastewater or even seawater before its return to the ocean. In parallel, efforts should focus on treating, using or diminishing the volume of brine disposed to surface water (Jones et al., 2019). Afrasiabi and Shahbazali (2011) discuss various advanced technological processes being studied for the treatment of brine, such as forward osmosis, vacuum membrane distillation and direct contact membrane distillation. Using the above methods in combination with reverse osmosis, a recovery rate of 89–98% can be achieved. Yet other methods seek to recover salts and nutrients from brine, producing commercial products and thus aiming to make treatment economically interesting (Dawoud & Al Mulla, 2012; El-Naas et al., 2010; Pérez-González et al., 2012; Pramanik et al., 2017). The ultimate aim of these methods is zero liquid discharge (Xevgenos et al., 2016).

Energy demand

The issue of energy demand was not perceived as a high concern in Antofagasta; however, the literature suggests that the water–energy nexus is becoming key to providing both water and energy sustainability as the security of both is becoming fundamentally linked (Goh et al., 2017; Hamiche et al., 2016; Shahzad et al., 2017). The reduction of costs and the carbon footprint of desalination lies in the improvement of energy efficiencies through recovering/reusing waste energy and the application of renewable energy (Goh et al., 2017; Li et al., 2018). With regards energy efficiency, energy-saving measures such as variable frequency controls for high-pressure pumps are essential. Energy recovery devices can be used to exploit reject brine pressure, with the potential to recover up to 50% of energy consumed (Goh et al., 2017). Such a device is implemented in Antofagasta, though the recovery rate is believed to reach 30% (on site visit 2019). Local, regional or national binding standards should be imposed for the implementation of energy saving and energy recovery devices on all desalination plants installed.

The use of renewable energy alternatives to supply the high energy demands of desalination is essential for mitigating environmental impact (Xevgenos et al., 2016). This can be achieved through multiple levels of governance simultaneously. For a desalination system connected to the national electrical line, such as the case of Antofagasta, the national distribution of energy sources is most relevant. For such a scenario, policies at a national level must be developed to promote the transition to clean energy production and the decarbonization of the network. Simultaneously, available alternatives of renewable energy should be produced and utilized at local or regional scales to enhance the security of drinking water provision. To promote this national or regional binding guidelines or norms for the share of renewable energy used for desalination can be introduced.

An interesting less developed alternative is the ocean as a source of energy, presenting some advantages particular for use in desalination plants. Most desalination plants are located in proximity to the ocean, reducing costs of transport. Ocean energy supply is predictable and constant and is the densest among renewable energy sources (Li et al., 2018). Additionally, some of the forms of ocean energy can be directly integrated with desalination processes and infrastructural installations, as such presenting potential for 'hybrid desalination' (Goh et al., 2017; Xevgenos et al., 2016). Such systems can theoretically decrease specific energy consumption of a seawater reverse osmosis system by 40–58% while also contributing to the reduction of brine discharged to the ocean. The potential of ocean energy in combination with desalination plants to ensure a water–energy nexus is undoubtedly very promising. However, such installations are yet mostly in the form of a pilot, involving considerable investment costs and challenges of scaling. Integration of this technology is likely to become feasible in the next decades (Li et al., 2018), but its infrastructural implications should be considered for long-term planning.

Reflection upon other City Blueprint Approach case studies

The case studies conducted in Quito, Bogota (Schreurs et al., 2018), and the City of Cape Town, South Africa (Madonsela et al., 2019), like this study, applied the City Blueprint Approach to evaluate integrated water management in metropolitan semi-arid cities. Though situated in varying geological and demographic contexts, there are important reflections to be made when contrasting these diagnoses. It is observed that whether water-related urban issues have been a severe stressor in the past or if they are a recent threat, water scarcity is only recently becoming a priority on political agendas. Important innovations are being implemented across the globe; however, as Schreurs et al. (2018) conclude, adaptation to climate change 'is not just a matter of technology'. The importance of participation principles, cross-stakeholder learning initiatives and an environment of trust for effective collaborations among institutions and the public cannot be underestimated. Public awareness of the water system, responsible consumption and use of sanitary infrastructure requires strengthening to narrow the gap between expert opinions and citizen perceptions. Tariff structures are an important area of improvement across studies, and volumetric charges (such as increasing fee for large commercial consumers in proportion to their consumption) are proposed. A key precondition is that drinking water must be affordable for everyone at all times (Grafton et al., 2011). Furthermore, these case studies demonstrate that drinking water security, stormwater treatment and wastewater treatment require integrated solutions, especially under water-stressed conditions. For instance, the construction of grey water systems, rainwater harvesting and the reuse of treated wastewater for non-potable purposes can be an important factor in reducing water stress and optimizing the use of available water resources. Finally, cities are advised to anticipate and adapt to changing and uncertain conditions in the contexts of climate change.

Conclusions

Desalination is generally applied to meet rising water demands in water-stressed regions, where freshwater sources are no longer sufficient. Nonetheless, it is associated with important limitations that can challenge water governance, namely issues of water quality perception, environmental pollution and high energy demands. Our study on Latin America's largest desalination plant for human consumption in the Chilean city of Antofagasta sheds light on how to improve the management and governance capacity to address water scarcity in similar urban hubs. Results indicate that in order to overcome negative perceptions of water quality, water utilities have to implement strict limits on organoleptic parameters, improve the trust of consumers and strengthen the relationship between consumers, operators and regulators through transparent and intelligible communication. Regarding the environmental impacts of desalinization, these are generally neither well known nor perceived as urgent, thus little effort has been made to promote solutions to environmental pollution and energy consumption associated with the function of desalination plants. Based on our findings we recommend appropriate ecological monitoring and the evaluation of brine treatment methods, while the use of (or transition to) the use of renewable energy sources is necessary for diminishing greenhouse gas emissions associated with the high energy demand of desalination.

Finally, another drawback stemming from the implementation of desalinization is that it can lead to a perceived abundance and comfort within the supply network, offsetting prior efforts for water-use efficiency in water-stressed regions. An integrated and coordinated approach seems crucial for ensuring sustainable and equitable water provision and customer satisfaction. From our case study findings, we provide the following transferable lessons in the form of a priority ladder of water management principles for the correct and efficient response to increasing water scarcity in water-stressed regions:

- Ensure access to drinking water for all: the expansion of the service network must be anticipated in line with the growth of cities and local urban planning.
- Enhance water conservation: consumption rates must be reduced both by enhancing domestic water conservation and by reducing system inefficiencies of pipeline leakages.
- Exploit the often untapped potential of wastewater reuse: under water-stress conditions, fit-for-purpose water reuse must be implemented, recognizing that wastewater is a largely untapped resource that has much potential to alleviate water stress. For this, a legislative framework is required that applies quality criteria per use category independently of the water's origin.
- Explore renewable water resources: additional water resources may provide a solution to meet rising water demands if water conservation and wastewater reuse have been considered first.
- Desalinate to address the remaining water deficit: if the above measures have been taken and water scarcity remains an issue, the implementation of desalination can be the next responsible step for meeting water demand in water-stressed regions.

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