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Unconventional Water Resources

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Executive Summary

Water scarcity is recognized as a key challenge to sustainable development and as a potential cause of social unrest and of conflict within and between countries. Water scarcity also impacts traditional seasonal human migration routes and, together with other water insecurity factors, could reshape migration patterns. Around 60% of the global population lives in areas of water stress where available supplies cannot sustainably meet demand for at least part of the year. As water scarcity is expected to continue and intensify in dry and overpopulated areas, the world at large is in danger of leaving the water scarcity challenge to future generations who will be confronted with the consequences of today's practices. Thus, water-scarce areas must sustainably access and utilize every available option for water resources in order to minimize the pressure that continues to grow.

> **The world at large is in danger of leaving the water scarcity challenge to future generations who will be confronted with the consequences of today's practices.**

Conventional water provisioning approaches that rely on snowfall, rainfall, river runoff and easily accessible groundwater are overexploited and insufficient to meet growing freshwater demand in water-scarce areas. Considering the water-related sustainable development challenges in arid regions, utilizing unconventional water resources are an emerging opportunity to narrow the water demand-supply gap. There are fragmented, but growing examples of unconventional water resource use across the world supplementing water supplies in order to address water scarcity.

> **Water-scarce countries need a radical re-thinking of water resource planning to include the creative exploitation of unconventional water resources for sustainable development.**

There is a multitude of unconventional water resources that can be tapped. Sources of unconventional water resources range from Earth's seabed to its upper atmosphere, and capturing them requires a diverse range of technological interventions and innovations. Harvesting water from the air consists of rain enhancement through cloud seeding and collection of water from fog, while capturing water on the ground addresses micro-scale capture of rainwater where it would otherwise evaporate; all these techniques address local water shortages. On the groundwater front, tapping offshore and onshore deep groundwater and extending sustainable extraction of undeveloped groundwater are important options in areas where there is potential for additional

Unconventional water resources range from the seabed to the upper atmosphere and utilizing them requires technological interventions.

groundwater resources. Reusing water is the key to water conservation and enhancement opportunities which lead to fit-for-purpose use of treated municipal wastewater and agricultural drainage water. Additional opportunities to develop water resources exist in the form of desalinated potable water. Physical transport of water, such as through towed icebergs and ballast water held in tanks and cargo holds of ships, is receiving attention, but corresponding practices remain in infancy.

The volumes of some unconventional water resources, such as municipal wastewater and desalinated water are known (380 km³ and 35

Unconventional water resources are essential in building a water future in dry areas where water is recognized as a precious resource and a cornerstone of the circular economy.

km³ respectively), and there are broader estimates available for deep groundwater volume at 16-30 million km³. Of this amount, 0.1-5.0 million km³ is less than 50 years old and renewable, while the remaining nonrenewable but larger volume is embedded in deep geological settings found both offshore and onshore. The earth's atmosphere contains about 13,000 km³ of water in a vapor phase, the source of which is evaporation from the surface of the oceans, seas, moist soil and plants. Antarctic ice contains 27 million km³ of water, of which 2,000 km³ break off annually as icebergs. Seawater stands at 1.35 billion km³. Accessing a minor fraction of such gigantic volumes of deep groundwater, atmospheric water, Antarctic ice, and seawater can help alleviate water scarcity in dry areas.

The fate of some unconventional water resources, such as towed icebergs and ballast water, is difficult to evaluate due to lack of practice, and the development of future scenarios and projections utilizing these resources is likewise difficult. Some resources such as fog water and rainwater harvested in micro-catchments produce very small volumes compared with some major unconventional water resources, but they provide critical support to the associated communities for addressing local water shortages.

Unconventional water resources can narrow the water demand-supply gap but, given the limited consolidated information and data, quantification of how far such water resources can bridge this gap at different scales remains a challenge and a valid question to address. In addition, despite demonstrated benefits, the potential of most unconventional water resources is vastly under-explored due to various barriers.

Given recurring water scarcity in dry areas and water table declines due to overexploitation, the time has come to consider strategies for sustainable water resources augmentation through realizing the potential of unconventional water resources, while also addressing barriers with associated response options by facilitating an enabling environment. The key elements of such a strategy would require the following actions: (1) assess the potential of augmenting current water supplies with unconventional water resources in water scarce areas; (2) revisit and make country- and area-specific unconventional water resource(s) a priority in political agendas, policies, and management of water resources in water-scarce countries and river basins, and enable their use through supportive action plans; (3) guide institutional strengthening and collaboration to avoid fragmented approaches and clarify roles and responsibilities of water professionals and institutions; (4) understand and analyze the economics of action and inaction to overcome the perception of high costs by undertaking comprehensive analyses of innovative financing mechanisms, the cost of alternate options (such as tankers or water transportation from wells from far distances), and economic and social costs; (5) build capacity of skilled human resources to address the complexity of assessing and utilizing some unconventional water resources along with their environmental, ecosystem, and economic tradeoffs; (6) encourage private sector investment in projects utilizing unconventional water resources; (7) engage communities to enhance local interventions with context-specific knowledge and integrate gender mainstreaming objectives and processes in community-based projects, and (8) support increased scientific funding to understand and tap the potential unconventional water resources in water-scarce regions.

The world needs to enter a new era of water management where the barriers to efficient water management gradually fade and where unconventional water resources in all forms are monitored, digitized, accounted for.

Water is increasingly considered as an instrument for international and transboundary cooperation to support food production, livelihoods, ecosystems, climate change adaption and mitigation, and sustainable development. Therefore, opportunities for international, regional, transboundary and country-level collaboration in harnessing the potential of unconventional water resources are crucial in an era when the world at large is not on track to achieve Sustainable Development Goal (SDG) 6 and water-related targets embedded in other SDGs by 2030. The good news is that water professionals and policymakers worldwide have started considering the role of unconventional water resources in building a future where water is recognized and treated as a precious, highly valuable resource and as a cornerstone of the circular economy. Such focus needs to continue and intensify with the possibility of a collaboration platform along with on-the-ground projects in water-critical areas to connect water experts, practitioners, young professionals, private sector, media, and policymakers to learn and exchange knowledge and practices to catalyze harnessing the potential of unconventional water resources. Social media can also play a major role in promoting the importance of unconventional water resources, especially in arid and semi-arid regions.

Social media can play a major role in promoting the importance of unconventional water resources in arid and semi-arid regions.

Context and Outlook

The world is faced with a growing number of complex and interconnected challenges. Water is among the top five global risks in terms of impacts, reaching far beyond socio-economic and environmental challenges and impacting livelihoods and wellbeing of the people (World Economic Forum, 2020). Because freshwater resources and population densities are unevenly distributed across the world, some regions and countries are already water scarce (Djuma et al., 2014). Around 60% of the global population lives in areas of water stress where available supplies cannot sustainably meet demand for at least part of the year (Damania et al., 2017). Global water scarcity is set to continue and intensify in dry and overpopulated areas. Global warming compounds this problem by potentially altering global hydrological cycle patterns, especially in arid areas (Famiglietti et al., 2015; Damania et al., 2017).

Water is among the top five global risks in terms of impacts, which would be far reaching beyond socio-economic and environmental challenges, impacting livelihoods and wellbeing of the people.

As stated above, increasing water scarcity is recognized as a key challenge to sustainable development and as a major cause of social unrest and of conflict within and between countries. It can also contribute to changes in traditional seasonal human migration routes and reshape migration patterns (Mach, 2017; Tignino and Mach, 2018; IOM, 2020). While this is happening, water is increasingly considered as an instrument for international cooperation to achieve sustainable development (Farnum, 2018). Sustainably assessing and tapping every available option in dry areas is necessary as pressure continues to build on limited water resources.

The stark fact is that conventional water provisioning approaches that rely on snowfall, rainfall and river runoff and easily accessible groundwater are not enough to meet growing freshwater demand in arid and semi-arid areas. Water-scarce countries need a radical re-thinking of water resource planning and management that includes the creative exploitation of a growing set of viable but unconventional water resources for food production, livelihoods, ecosystems, climate

There are fragmented, but growing examples of using unconventional water resources across the world to boost water supplies in dry areas.

change adaption, and sustainable development and conservation. This is especially relevant in transboundary basins where joint dialogue and action are needed to address water scarcity.

Unconventional water resources are by-products of specialized processes, may need suitable pre-use treatment, require pertinent on-farm management when used for irrigation, or result from specific techniques to collect/access water (Qadir et al., 2007). Key unconventional water resources include, but are not limited to, the following:

- Atmospheric moisture harvesting such as cloud seeding and fog water collection;
- Micro-scale capture of rainwater where it would otherwise evaporate;
- Groundwater confined in onshore deep geological formations or in offshore aquifers;
- Water from urban areas including municipal wastewater and storm water;
- Residual water from agriculture, such as agricultural drainage water;
- Ballast water held in tanks and cargo holds of ships to increase stability during transit;
- Icebergs collected from arctic regions and transported to water-scarce areas; and
- Desalinated seawater and brackish groundwater.

There are fragmented but growing examples of using unconventional water resources across the world to boost water supplies as a means of addressing water scarcity (Smakhtin et al., 2001; Qadir et al., 2007; Djuma et al., 2014). However, despite demonstrated benefits, the potential of most unconventional water resources is vastly under-explored due to the lack of consolidated information on the significance of such water resources. In addition, there are multiple barriers to harnessing the potential of these water resources that need to be addressed through supportive policies and institutions, science-based actions and tools, and innovative financing. These factors are the focus of this analytical brief, which is based on the following objectives:

- To highlight the linkages of unconventional water resources with the SDG 6 and other water-related SDGs in the context of food security, ecosystems, climate change adaptation and mitigation, and sustainable development;
- To evaluate the potential of unconventional water resources as a water augmentation resource in water-scarce areas;
- To address policies and institutions, economics, education, capacity building, community participation, and gender aspects of unconventional water resources; and
- To provide insight into the barriers and associated response options to facilitate the use of unconventional water resources, particularly in areas of physical water scarcity and areas approaching water scarcity taking into consideration transboundary perspectives.

This analytical brief is addressed to a range of audiences, particularly water-related policymakers, researchers, and private sector professionals dealing with issues stemming from water scarcity in dry areas. The brief is expected to contribute to a better understanding of the potential of unconventional water resources and to enhance knowledge of key challenges and opportunities in order to trigger harnessing the potential of such water resources in water-scarce countries.

Linkages with SDG 6 and other water-related SDGs

Achieving SDG 6 and water-related targets in other SDGs is a grand challenge for the world at large due to increasing water scarcity (Sustainable Development Knowledge Platform, 2018). Given the fact that most countries are not on track to achieve SDG 6 by the deadline set for 2030 (UN, 2018), a new water paradigm for water-scarce countries and river basins considering a range of unconventional water resources is crucially important for achieving water related sustainable development. There are close linkages of unconventional water resources with SDG 6 and its targets and water-related targets in other SDGs:

Collaboration across water-scarce areas is crucial in harnessing the potential of unconventional water resources at a time when most countries are not on track in achieving SDG 6 by 2030.

- **SDG 6.1:** *achieving universal and equitable access to safe and affordable drinking water for all*. Unconventional water resources such as fog water collection, desalinated water, transportation of water through icebergs and ships' ballast water, and groundwater confined in deep land-based geological formations or in off-shore aquifers can provide enough potable water in areas where water is scarce or the quality of available water resources does not meet drinking water quality standards.

- **SDG 6.3:** *improving water quality by reducing pollution, eliminating dumping and minimizing the release of hazardous chemicals and materials, halving the proportion of untreated wastewater and substantially increasing recycling and safe reuse globally*. Disposal of large volumes of untreated or inadequately treated wastewater to freshwater bodies has deteriorated the quality of water resources in arid regions where achieving SDG 6.3 via halving the volumes of untreated wastewater by 2030 would help improve water quality and provide a water resource in the form of treated wastewater that could be used in different sectors such as agriculture, aquaculture, agroforestry, aquifer recharge, and environmental flows.

- **SDG 6.4:** *substantially increasing water-use efficiency across all sectors and ensure sustainable withdrawals and supply of freshwater to address water scarcity and substantially reducing the number of people suffering from water scarcity*. The increase in water-use efficiency and water productivity supported by some unconventional water resources in arid regions would help reduce overall water scarcity and the number of people suffering from it. Examples include, but not limited to micro-scale capture of rainwater where it otherwise evaporates, capture and use of drainage water from irrigated areas, and water supply increase by rainfall enhancement via cloud seeding.

- **SDG 6.5:** *implementing integrated water resources management at all levels, including through transboundary cooperation as appropriate*. Efficient use of unconventional water resources can support implementing integrated water resources management in water-scarce countries as well as transboundary basins and ensure transboundary planning and actions to develop an environment supportive for new approaches harnessing the potential of unconventional water resources.

- **SDG TARGET 6.A:** promoting international cooperation and capacity-building support to developing countries in water- and sanitation-related activities and programmes, including water harvesting, desalination, water efficiency, wastewater treatment, recycling and reuse technologies. As explicitly mentioned in this SDG target, there is a need for international cooperation to support capacity-building activities for developing-country professionals in harnessing the potential of unconventional water resources.

- **OTHER WATER-RELATED SDGS:** SDG 1 on *ending poverty*, SDG 2 on *achieving food security*, SDG 3 on *ensuring healthy lives and wellbeing*, SDG 7 on *accessing affordable and sustainable energy for all*, and SDG 10 on *reducing inequalities within and among countries*. Improved supplies of quality water via unconventional water resources would support the achievement of these SDGs.

- **SDG 13:** *taking urgent actions to combat climate change and its impacts*. As lack of water is the key factor in triggering frequent drought events and its impacts, unconventional water resources could partially offset increased water needs because of increased temperature and extended periods of drought and increased frequency of extreme weather events will make management more difficult.

- **SDG 17:** *strengthening the means of implementation and revitalizing the global partnership for sustainable development*. Global and regional partnerships can foster uptake of promising and functional examples of unconventional water resources in dry areas.

Unconventional water augmentation opportunities in water-scarce areas

Unconventional water resources offer emerging opportunities to address water shortages in areas where sustainable access to water is unreliable and conventional water resources are limited. There are fragmented, but growing examples of using unconventional water resources across the world to boost water supplies to address water scarcity.

Fog water harvesting

Water embedded in fog is increasingly seen as a source of potable water to address local water shortages in dry areas where sustainable access to water is unreliable and rainfall is limited, but certain conditions must be present: fog events are frequent; fog concentration is high; winds are persistent such as trade winds from one direction (4-10 m/s = 14-36 km/h), and space and altitude are enough to intercept fog. Fog water collection is a passive, practical, low maintenance, and sustainable option that can supply fresh drinking water to communities where fog events are common (Qadir et al., 2018).

As part of the natural global water cycle, at any given time, the amount of water in the atmosphere is 12,900 km^3, which represents 0.001% of total water and 0.04% of freshwater existing in the planet (Graham et al., 2010). Under specific conditions, the air at ground level may contain fog, which refers to the presence of suspended liquid water droplets with diameters typically from 1 to 50 µm (Ritter et al., 2015). Fog originates from the accumulation and suspension of these tiny droplets of water in the air, creating masses of humid air over land or sea, and it has been identified as an important source of water in desert environments (Bhushan, 2019). Collection of fog is achieved by the collision of suspended droplets on a vertical mesh, where they coalesce, after which the water runs down into a collecting drain and into a tank or distribution system (Figure 1).

In general, fog collection systems are made up of polypropylene mesh nets, usually Raschel nets (Schemenauer and Cereceda, 1994; LeBoeuf and Jara, 2014). In areas where Raschel nets are too fragile to withstand heavy wind loads, other fabrics and configurations have been put in place. For example, three-dimensional spacer fabric is being used as a replacement for Raschel nets that tore in the harsh environment (Trautwein et al., 2016). The number, size and type of fog collectors installed in a specific location depend on the fog characteristics, such as fog thickness, duration and frequency of occurrence, as well as climate and topography of the area, water demand, and financial and human capacity of the associated community to run and maintain the fog collection system. Fog water yield largely

Figure 1 Fog water collection systems (Credit: Aqualonis).

depends on the fog intensity, duration, and frequency of fog events. Fog days range from 60 to 360 days on fog collection sites, and daily fog water yields range from 2 to 20 L/m² of fog water collection mesh (Correggiari et al., 2017).

Several dry mountainous and coastal regions are suitable to implement fog water collection systems. Site selection is the key to effective fog water collection and starts with two major assessment parameters. First, identification of potable water demand in areas where available water resources are far away, or where alternate sources are prohibitively expensive (e.g., water tankers). Second, meteorological studies of the target areas, which show that fog intensity and duration are suited to apply fog water collection systems. Based on these considerations, multiple sites around the world have been established to collect fog water for potable uses, and, to a limited extent, for livestock and agriculture.

Fog water collection projects have been undertaken in many countries, including Chile, Cape Verde, Eritrea, Guatemala, Nepal,

Sustainability of fog water collection systems relies on engaging local institutions and associated communities and ensuring gender mainstreaming.

Morocco, Peru, Namibia, South Africa, Saudi Arabia, Egypt, Azerbaijan, Ethiopia, Oman, Israel, Colombia, Yemen, Dominican Republic, Ecuador, and the Canary Islands. The largest fog collection project is installed in the Aït

Baamrane region in Southwest Morocco, where the arid ecosystem receives an annual rainfall of only 112 mm but experiences frequent fog events at an average of 143 days a year (Dodson and Bargach, 2015). Engaging local institutions and associated communities and ensuring gender mainstreaming are key drivers to ensure sustainability of fog water collection systems.

Rain enhancement through cloud seeding

The earth's atmosphere contains about 13,000 km^3 of water in a vapor phase, the source of which is evaporation from the surface of the oceans, seas, and soil moisture and transpiration from plants. These water vapor reserves are continuously updated due to the circulation of evaporation-condensation and precipitation, making annually 8-9 hydrological cycles, each lasting about 40-45 days (Bengtsson, 2010). Thus, the amount of water vapor present in the atmosphere is an inexhaustible freshwater source and opportunity for rain enhancement.

Under pertinent conditions, cloud seeding could be used to enhance rainfall in the target area. Above the earth in the lower and middle troposphere, cloud-seeding is a system that involves dispersing special glaciogenic or hygroscopic substances into clouds or their vicinity that allow water droplets or ice crystals to activate on heterogenous nucleus through water vapor condensation-freezing processes (Flossmann et al., 2019). Subsequent collision-coalescence growth between artificial and natural water droplets and ice crystals lead to formation of large rainy hydrometeor (drops, graupels, hailstones, snowflakes, etc.) that fall as precipitation. Cloud seeding involves the application of extensive technology for modification of the precipitation regime in clouds of various types, including convective storms, large scale stratus clouds and ground fogs. Estimates suggest that only up to 10% of the total cloud water content is released to the ground as precipitation, suggesting huge potential for rain enhancement technologies to increase precipitation formation efficacy (Abshaev et al., 2009).

Cloud seeding has been used for more than 50 years for the purpose of precipitation enhancement, hail suppression, fog dispersion and improvement of weather conditions over large cities during various sports events and celebrations (WMO, 2015). Higher in the troposphere, atmospheric 'rivers' (Gimeno et al., 2014) carry 90% of the north-south water vapor transport from the tropics through the lower troposphere in streams covering only 10% of the circumference of the earth (Ralph et al., 2017) but that can be hundreds of miles wide and over a thousand miles long (Shipman et al., 2016). While they deliver critically needed precipitation, atmospheric rivers can also cause floods, mudslides and landslides, and techniques for controlling atmospheric rivers have not yet been developed. However, there have been developments in the modeling, analytical, and observational capabilities, furthering scientific understanding of individual cloud processes and their potential interactions (Flossmann et al., 2019).

While scientific status of weather modification is steadily improving, limitations remain in detailed understanding of cloud dynamics and related microphysics.

Cloud seeding is usually done at the cloud base or cloud top or by direct introduction of the reagent at the desired height inside the cloud. In

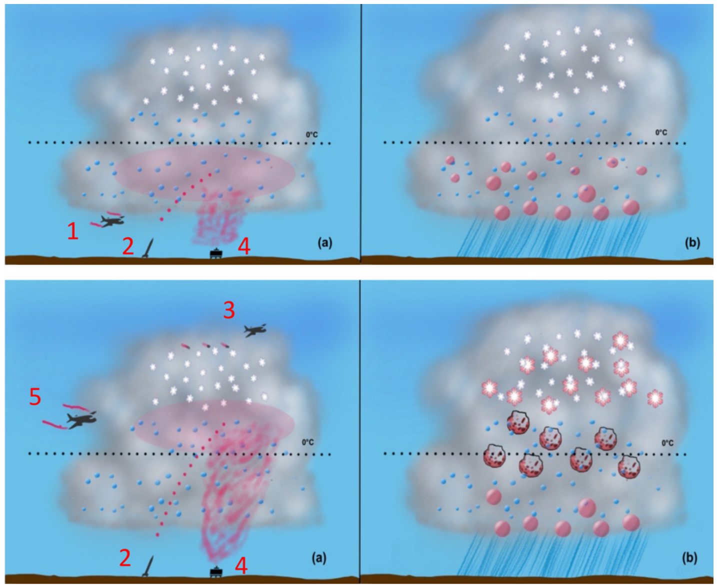


Figure 2 Rain enhancement through cloud seeding using aviation, rocket or ground-based generators of nuclei of crystallization or condensation: (a) refers to seeding options and (b) reflects on intended outcome of the seeding. The seeding options include: (1) Cloud-base aircraft seeding; (2) rocket seeding; (3) cloud-top aircraft seeding; (4) ground generator seeding; and (5) direct aircraft seeding by cloud penetration. (Flossmann et al., 2019; with permission from the American Meteorological Society).

various projects, reagent delivery is carried out by light and medium-size aircraft, small-sized ground-to-air and air-to-air rockets, artillery shells and ground generators (Figure 2). Air balloons with dropped payload and firework-type devices equipped with reagents have also been utilized. The selection of seeding strategy vastly depends on the type and characteristics of clouds, seeding materials and delivery method.

The main goal of all seeding technologies is the stimulation and/or acceleration of the formation of relatively large water and/or ice hydrometeors able to fall on the ground earlier than would happen naturally. Depending on the type of cloud and the area where the reagent was injected, this process can include condensation growth of water droplets and ice crystals due to the absorption of water vapor and collision-coalescence growth between drops, ice crystals, snowflakes, ice graupels and hail particles.

The types of clouds are important to the fate of cloud seeding. There are significant differences between continental clouds and clouds formed over the sea. Droplets in continental clouds are usually less optimal for collision-coalescence growth due to their smaller sizes and higher concentration. Since larger droplets are needed if rain is to form, this means that precipitation mode in continental clouds is more complicated than in maritime clouds.

Not all clouds are suitable for seeding, and the process is recommended only for those clouds that meet a set of special conditions, such as enough water content, vertical depth of cold and/or warm parts and development dynamics (Flossmann et al., 2019). The huge energy associated with natural cloud systems means that it is not feasible to enhance precipitation through changes to the mass or energy balance of the system, but only through unstable states in clouds (convective, phase and colloidal instabilities). Thus, only a precise knowledge of the system and a careful intervention via seeding with appropriate aerosol particles that augment or substitute for natural particles provide this opportunity to enhance precipitation from the clouds.

Artificial cloud seeding envisages a spray of specific aerosol particles into a cloud environment that competes with the naturally available particles for water vapor. Among these aerosol particles are ice-forming particles, such as silver iodide, which has a lattice structure like natural ice crystals, or alternative chemical compounds, such as salt-based hygroscopic particles with various additives, dry ice pellets or liquid nitrogen (Flossmann et al., 2019). Such seeding materials are often called reagents. There are large differences in the chemical compositions and variations of the reagents. Current research addresses optimizing reagents compositions and increasing their efficiency. To measure properties of reagents in laboratory conditions, specialized large and small cloud chambers of different types are commonly used, where it is possible to simulate temperature, humidity, liquid and ice water content, airflow, electrical fields and other parameters specific to the investigated cloudy environment. Freezing of water droplets and vapor condensation caused by seeding are accompanied by the release of latent heat, which forces buoyancy and thermal convection of clouds and thus contributes to their further growth.

Experience in applying cloud seeding technology in different countries has shown that precipitation can be increased, ranging from essentially zero to more than 20% of the annual norm depending on the available cloud resources and types, reagents types and delivery method, cloud water content and base temperature (Flossmann et al., 2019). Higher values tend to be associated with direct delivery of seeding materials to the clouds utilizing aircrafts and rockets. However, the reasons for the large variation in impacts are not well understood, and estimates of impact are sensitive to the estimation of the natural precipitation in the target area (Flossmann et al., 2019).

Micro-catchment rainwater harvesting

In regions where rainfall is limited and subject to high intra-and inter-seasonal variability, like arid and semi-arid regions, much of the rainwater that does fall is lost through surface runoff and evaporation. This is further aggravated due to poor vegetative cover and shallow and crusting soils. These factors provide a strong impetus for strategies that make the best use of even the small amounts of the rainfall and runoff water through micro-catchment rainwater harvesting systems for crop production and local needs of the associated communities (Oweis, 2017).

There are usually two major types of micro-catchment rainwater harvesting systems. The first system is water harvesting via rooftop systems where runoff is collected and stored in tanks, cisterns, or similar devices. This water is used domestically or for livestock watering, but water quality issues are of concern especially in domestic use (Oweis, 2017). The second system is water harvesting for agriculture, which involves collecting the rainwater that runs off a catchment area in a reservoir or in the root zone of a cultivated area, which is usually smaller than the size of the catchment

In rainfall-limited areas, micro-catchment rainwater harvesting systems can support local needs of the associated communities.

Figure 3 Micro-catchment rainwater harvesting systems (Credit: Theib Oweis, ICARDA).

area (Figure 3). Owing to the intermittent nature of runoff events, it is necessary to store the maximum amount of rainwater during the rainy season so that it can be used later (Thomas et al., 2014).

Micro-catchment rainwater harvesting systems, also called in situ water harvesting, have a relatively small surface runoff catchment (from a few square meters to a few thousand square meters) where sheet flow travels short distances (Previati et al. 2010). Runoff water from the catchment is usually applied to an adjacent agricultural area to be stored in the soil profile for use directly by the plants or in a small catchment for later use by humans or animals. The catchment surface may be natural or treated with one of the runoff-inducing materials, especially in areas with sandy soils having high infiltration rates (Oweis, 2017).

Different forms of micro-catchments have been used for agriculture. Contour bunds consist of earth, stone or trash embankments placed along the contours of a sloping field or hillside in order to trap rainwater behind them and allow greater infiltration. Semicircular, trapezoidal or ‘V’- shaped bunds are generally placed in a staggered formation, allowing water to collect in the area behind the bunds. Excess water is displaced around the edges of the bund when the ‘hoop’ area is filled with water. These systems are most commonly used for growing fruit trees or shrubs (Qadir, et al. 2007). Another type of water harvesting system involving micro-catchments is the meskat-type system, where, instead of alternating catchment and cultivated areas, the field is divided into a distinct catchment area that is located directly above the cropped area. The catchment area is often stripped of vegetation to increase runoff. The cultivated area is surrounded by a ‘U’- shaped bund in order to hold the runoff. In Tunisia, olive trees are grown in these systems. A similar system ‘Khushkaba’ is used in Baluchistan province of Pakistan for growing field crops (Oweis et al., 2004).

Offshore deep groundwater

Shallow groundwater resources are being exploited at rates that exceed modern recharge estimates (Aeschbach-Hertig and Gleeson, 2012). Current annual global estimates of groundwater pumping are 750-800 km³ (Konikow and Kendy, 2005). In urban areas and agricultural regions, over-pumping has resulted in tens of meters of water table drawdown, land subsidence and salinization (Galloway et al. 1999; Mohamed et al., 2016; Werner et al., 2013). Estimates of the total available groundwater on earth are between 16-30 million km³ (Gleeson et al., 2016). Only about 0.1-5.0 million km³ of this are shallow resources (Ferguson et al., 2018) less than 50 years old and renewable (Gleeson et al., 2016). The larger volume is hosted in deep (up to 1 km) regional aquifer systems or in offshore settings.

Offshore freshwater refers to water hosted in aquifers that are beneath the seafloor. The technology developed for offshore oil and gas exploration and extraction would be transferable to offshore aquifers, making them immediately accessible under the right (mostly economic) circumstances. The enormous quantities of fresh to slightly brackish water in offshore aquifers can provide an attractive return on investment when the cost of land-based freshwater rises to the point where developing offshore freshwater makes economic sense (Martin-Nagle, 2020).

Over the past 50 years, drilling on the continental shelf has revealed the existence of offshore fresh and slightly brackish offshore fresh groundwater (Hathaway et al., 1979) (Figure 4). Such water is found at marine depths of less than 600 m and distances of less than 100 km beneath a fine-grained confining unit. The range of offshore freshwater volume is between about 0.8 to 9.0 km³/km of coastline.

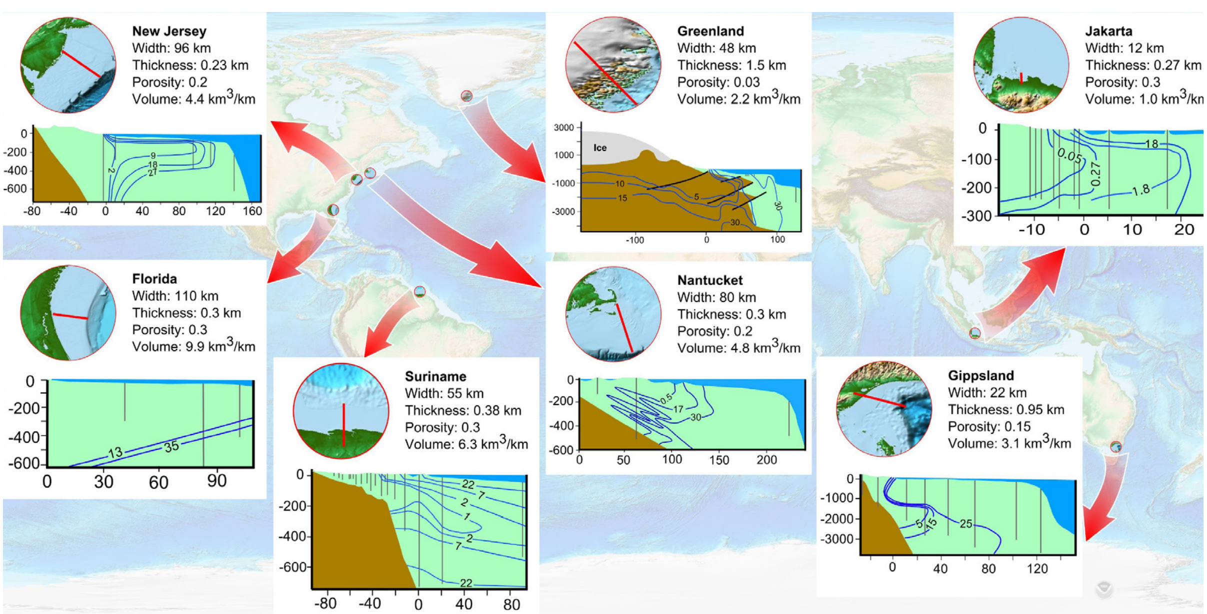


Figure 4 Cross sections showing the occurrence of vast meteoric groundwater reserves (VMGRs) around the world. The blue lines are contours of salinity in parts per thousand. Gray vertical lines are offshore well locations (Post et al., 2013).

Estimates reveal that up to 5 × 10^5 km³ of fresh to brackish water (< 1 ppt) are sequestered in shallow (< 500 m) permeable sandstone and limestone reservoirs (Cohen et al., 2010; Post et al., 2013). For comparison, the total

Current extraction of deep groundwater from confined aquifers is limited to mining process and more research is needed to scale up its extraction for potable water use.

estimated annual groundwater withdrawal from onshore aquifers within the United States in 2015 was 117 km³ (Dieter et al., 2018).

While the notion of large-scale development of offshore freshwater is relatively new (Person et al., 2017), offshore freshwater utilization has been going on for millennia through submarine groundwater discharge. During the first century Common Era (CE), for example, the Greek geographer Strabo reported the utilization of offshore freshwater springs near Arwad, Syria (Moosdorf and Oehler, 2017).

Although submarine groundwater discharge and offshore aquifers represent two different types of offshore freshwater resources, both should be explored more carefully.

Offshore freshwater aquifers are perhaps best studied and documented on the east coast of the United States (e.g. New Jersey, Martha's Vineyard; Figure 4), where extensive drilling and testing have been conducted between the 1970s and 2010. This freshwater was emplaced when sea levels were much lower in the last 2.5 million years as enormous ice sheets extended across the continents (Cohen et al., 2010). During the last glacial maximum, for example, sea-level was 120 m lower than present-day conditions; on average, sea level has been 40 m lower than the present (Person et al., 2003).

Marine magnetotellurics and controlled source electromagnetic methods have recently been developed that can image offshore freshwater (Figure 5). Such technological innovations could be deployed around the globe to characterize offshore freshwater and lower drilling exploration costs (Gustafson et al.,

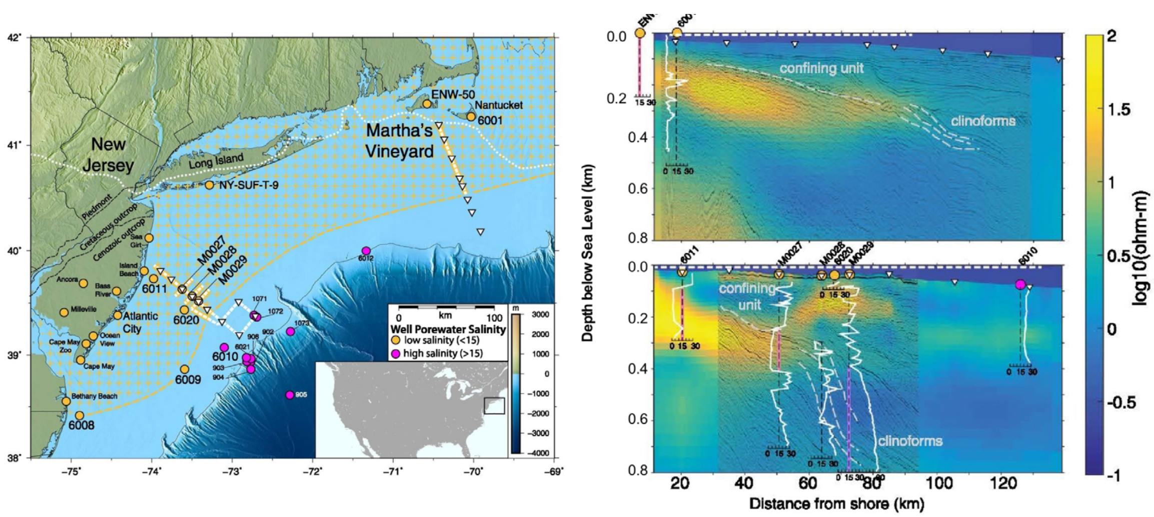
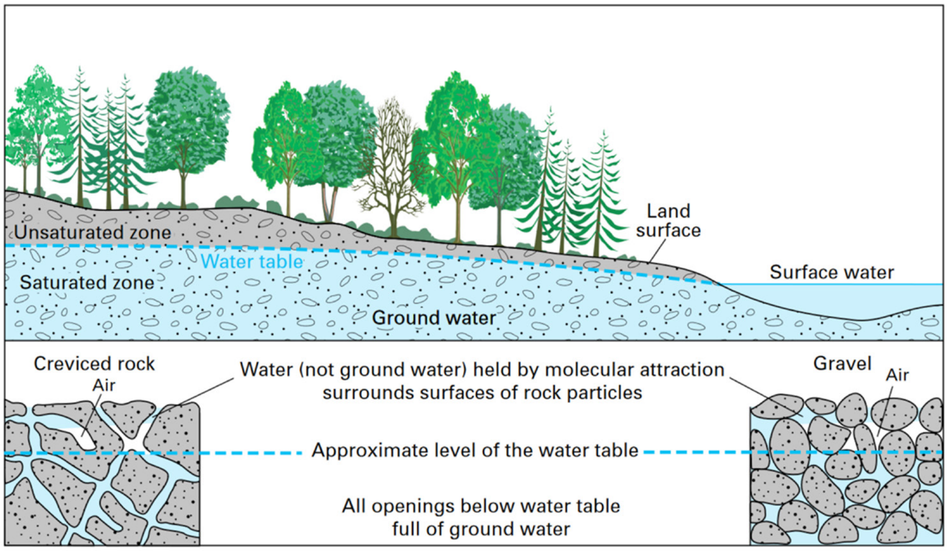


Figure 5 Base map showing location of high (pink) and low (yellow) salinity offshore wells and location of marine EM surveys (a) and joint electromagnetic controlled source and magnetotelluric inversion of offshore freshwater along Martha's Vineyard (b) and New Jersey (c) (Gustafson et al., 2019; Open access under the terms and conditions of the Creative Commons Attribution).



How ground water occurs in rocks.

Figure 6 Groundwater in confined geological formations (Credit: U.S. Geological Survey; Open Access).

2019; Micallef et al., 2020). Offshore freshwater is a poor conductor of electricity having a formation electrical resistivity of about 100 Ohm-m. Production of offshore freshwater using horizontal wells could permit daily production of offshore freshwater at substantial rates (19,200 m³) over 30 years provided that the freshwater is capped by a relatively tight confining unit (Person et al., 2017). Horizontal drilling technology advancements are lowering drilling costs. One potential candidate site could be Cape Town, South Africa, which saw an extended drought period in 2017. There is concern that offshore production might affect onshore water resources and land subsidence (Yu and Michael, 2019). To date, no offshore freshwater resources have been developed.

Onshore deep groundwater

One source of onshore freshwater is the groundwater from confined aquifers and fossil aquifers (Figure 6). An aquifer below the land surface that consists of saturated porous rock sandwiched between two impermeable layers is a confined aquifer. Layers of impermeable material both above and below the aquifer cause it to be under pressure and, when the aquifer is penetrated by a well, the water rises above the top of the aquifer. Similarly, fossil aquifers can be defined as geological formations containing fresh groundwater where the water was emplaced thousands to millions of years ago with little to no recharge in contemporary times (Foster and Loucks, 2006). If a well is drilled into a “pressurized” aquifer, the internal pressure might (depending on the ability of the rock to transport water) be enough to push the water up the well and up to the surface without the aid of a pump, sometimes completely out of the well. This type of well is called artesian.

Located on land, the onshore fossil aquifers can be found between low-permeable confining layers and can also be in unconfined formation far below the surface where no recharge is possible. Most of the Ogallala Aquifer in the United States is an example of the former type

Figure 7 Municipal wastewater is a valuable source of water, nutrients and energy, but large volumes are released to the environment in untreated form. Farmers in dry areas pump this water to irrigate close-by fields (Credit: Manzoor Qadir).

(North Plains Groundwater Conservation District, 2019), and the Nubian Sandstone Aquifer System in Northern Africa is an example of the later type (Mohamed et al., 2016). These aquifer systems have received relatively high recharge rates during the past 2.5 million years when the climate was, on average, cooler and wetter in those areas (Putnan and Broecker, 2017). Since these aquifers receive relatively low volumes of recharge today, any extraction can be viewed as mining the resource. These ancient confined waters could be viewed as a vital resource that is sequestered in a terrestrial bank, safely stored for future generations (Martin-Nagle, 2011).

Municipal wastewater

Municipal wastewater is generated as a possible combination of (1) domestic effluent consisting of black water from toilets, greywater from kitchen and bathing and other household uses; (2) waste streams from commercial establishments and institutions; (3) industrial effluent where it is discharged into the municipal sewerage systems; and (4) stormwater and other urban runoff ending up in municipal sewerage systems (Figure 7).

Population growth and urbanization have facilitated higher living standards resulting in an increase in water demand and, consequently, greater volumes of wastewater production. This scenario suggests that more and more wastewater will be available in coming years, revealing an opportunity to address water scarcity in dry areas through the collection, treatment and fit-for-purpose use of wastewater in agriculture, aquaculture, agroforestry/landscaping, aquifer recharge and direct or indirect potable use.

Once stigmatized as waste, municipal wastewater is increasingly recognized as a valuable source of water, nutrients, precious metals, and energy. There is a proactive interest in recovering water, nutrients and energy from municipal waste streams with the increase in

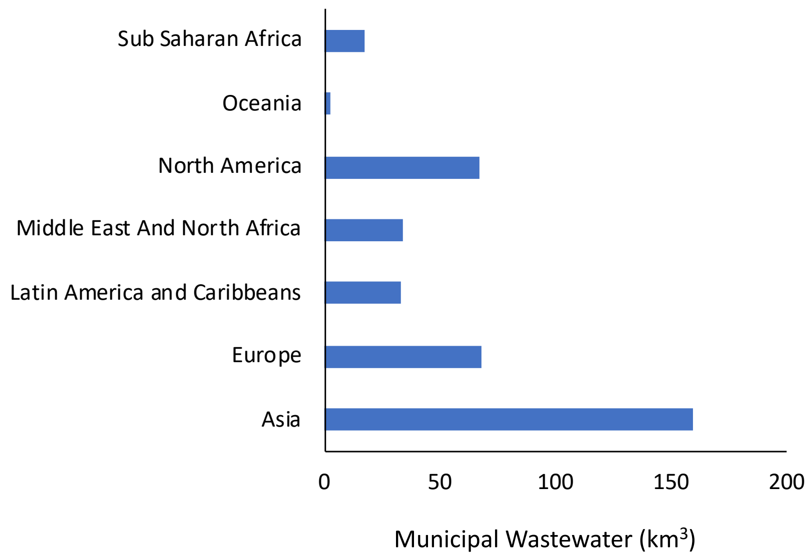


Figure 8 Municipal wastewater production across regions with Asia producing about 40% of global wastewater volume (Calculated based on the data from Qadir et al., 2020).

municipal wastewater volumes and innovations in resource recovery. Estimates suggest that 380 km^3 of wastewater are produced annually across the world, which is a volume more than 5-fold the volume of water passing through Niagara

Collection, treatment, and fit-for-purpose use of wastewater bring multiple benefits: recovery of water, nutrients, and energy; environmental conservation; and productivity enhancement.

Falls annually (Figure 8). Wastewater production globally is expected to increase to 470 km^3 by 2030 and 575 km^3 by 2050. Among major nutrients, 16.6 tera-gram (Tg = million metric ton) of nitrogen are embedded in wastewater produced worldwide annually; phosphorus stands at 3.0 Tg and potassium at 6.3 Tg. The full nutrient recovery from wastewater would offset 13.4% of the global demand for these nutrients in agriculture. Beyond nutrient recovery and economic gains, there are critical environmental benefits, such as minimizing eutrophication and reducing the pressure on natural resources.

At the energy front, the energy embedded in wastewater would be enough to provide electricity to 158 million households. These estimates and projections are based on the maximum theoretical amounts of water, nutrients and energy that exist in the reported municipal wastewater produced worldwide annually (Qadir et al., 2020).

Despite the importance of valuable resources embedded in municipal wastewater and even though water reuse projects are ongoing in some countries (Jimenez and Asano, 2008), the potential of recovering these resources from waste streams remains under-explored. Most developing countries have not been able to build wastewater treatment plants on a large enough scale and, in many cases, they were unable to develop sewer systems fast enough to meet the needs of their growing urban populations. As a result, in several countries, particularly in

Sub-Saharan Africa, sanitation infrastructure in major cities has been outpaced by population increases, making the collection and management of urban wastewater ineffective. The implementation of the Directive 91/271/EEC within the European Union has led to a significant increase in the percentage of people connected to urban wastewater treatment systems.

The good news is that a shift is underway in research and practice supporting collection, treatment and fit-for-purpose and productive use of treated municipal wastewater (Qadir et al., 2020). This would need to review potential treatment options based on specific sources of municipal wastewater production and its fit-for-purpose use or safe disposal methods. Harnessing the potential of resource recovery from municipal wastewater would need actions beyond technical approaches, exploring the business opportunities for resource recovery and reuse (Otoo and Drechsel, 2018). There is a need to facilitate and expedite implementation of resource recovery innovations particularly in low- and middle-income countries where most municipal wastewater still goes into the environment untreated (Wichelns and Qadir, 2015). As the demand for freshwater is ever-growing and scarce water resources are increasingly stressed, ignoring the opportunities leading to resource recovery in safely managed wastewater systems is nothing less than unthinkable in the context of a circular economy (UNESCO and WWAP, 2017).

Agricultural drainage water

Adequate drainage is a prerequisite if irrigation is to be sustainable, particularly when salts in groundwater and high-water tables or waterlogging may damage the crops. A fraction of the water used for crop production results in drainage water, which contains salts and the residues of agro-chemicals such as pesticides, fertilizers, and soil and water amendments. To maintain an appropriate salt balance in the topsoil layer, which makes up the effective root zone, the salinity of the drainage water percolating below the root zone must be higher than the salinity of the irrigation water applied (Qadir et al., 2007).

Irrigation with agricultural drainage water needs salt management, but results in agricultural productivity, carbon sequestration, economic, and livelihoods gains.

In arid and semi-arid regions, irrigation has been an important factor in agricultural development and the expansion in irrigated agriculture needs to continue as the world population increases, but annual renewable freshwater resources are now largely allocated. Intense competition for freshwater already exists among the municipal, industrial, and agricultural sectors in water-scarce countries. The consequence has been a decreased allocation of freshwater to agriculture, a phenomenon that is expected to continue and to intensify in less developed, arid region countries that already have high population growth rates and suffer from serious environmental problems. In such countries, the reuse of agricultural drainage water has become an important source of irrigation. Contingent upon the levels and types of salts present, and the use of appropriate irrigation and soil management practices, agricultural drainage water can be used for different crop production systems (Oster and Grattan, 2002; Linneman et al., 2014).

By recycling saline water until it is no longer unusable for any economic activity and by returning salt-affected irrigated areas to higher

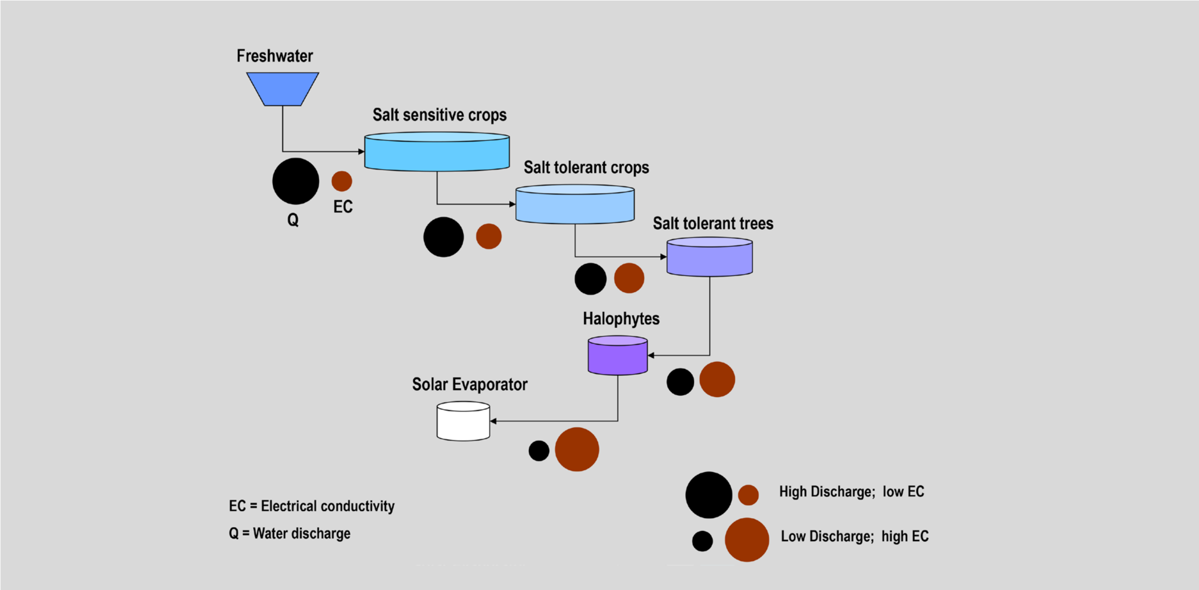


Figure 9 Sequential reuse of saline drainage water can contribute significantly to food, feed, renewable energy production, and carbon sequestration in soils.

levels of production, a significant contribution to food, feed and renewable energy production could be achieved without expanding the production area and obviating the associated challenges that this brings (Figure 9). There is a need for a paradigm shift towards the reuse of saline water until it becomes unusable for any economic activity rather than its disposal. In doing so, there are additional gains in the form of mitigating climate change impacts through enhanced soil carbon sequestration. Therefore, saline drainage water cannot be considered as redundant and consequently neglected, especially in areas that are heavily dependent on irrigated agriculture where significant investments have already been made in infrastructures such as water conveyance and delivery systems to supply water for irrigation and food security.

Two generic options for local management of saline drainage waters are (1) disposal to evaporation basins for regional storage and (2) reuse for irrigation. In the first case, there is the missed opportunity to productively utilize saline drainage waters and such an approach should only be considered where the productive use of these waters is deemed to be economically unsuitable. In the latter case, the reuse of drainage water to directly irrigate downstream crops by traditional irrigation methods is less sustainable than the original irrigation water as the drainage water contains higher concentrations of salts than the applied irrigation water. Thus, in the irrigation scheme relying on drainage water reuse and including final use to irrigate halophytes (Figure 8), all irrigation steps require overirrigation to generate drainage water to be collected in a tile drainage system; the sustainability hinges on community involvement in design and governance of the irrigation scheme; and the need to use hydrologic and ecological models at the river basin scale as tools to assess long-term consequences of different alternatives in using various sources of water.

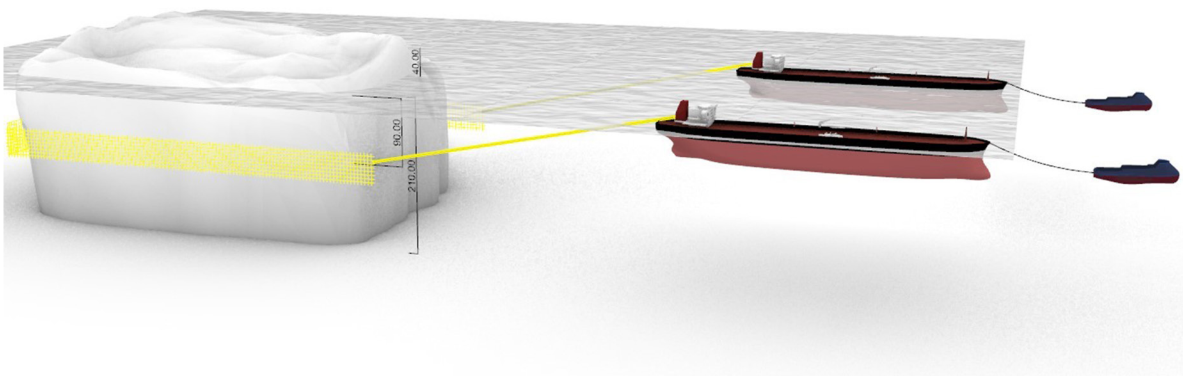


Figure 10 Schematic presentation of iceberg towing technology (Credit: Nicholas Sloane, Southern Ice Forum).

Water transportation through iceberg towing

An iceberg is a massive chunk of ice that is calved from a continental glacier due to wave action and subglacial stress. Icebergs can provide a substantial, constantly renewable, and potentially environmentally neutral untapped freshwater source. Approximately 75% of the world's freshwater is held in ice, and of that volume, approximately 90% sits in the Antarctic. The total volume of Antarctic ice contains 27 million km³ water, of which annually about 2,000 km³ break off as icebergs (Lewis, 2015).

Towing an iceberg from one of the polar ice caps to a water-scarce country in need may not seem like a practical solution to water shortages, but scientists, scholars and politicians have been considering iceberg-harvesting as a potentially viable freshwater source since the 1950s (Lewis, 2015). Furthermore, iceberg towing technology is available as Canadian oil and gas industry regularly tows icebergs away from offshore platforms when there is a risk of collision. Although it has not yet been carried out on a large scale, the increasing need for freshwater around the world, the continued abundance of icebergs, and the advancements in technology and science for iceberg harvesting, might soon expedite the efforts to make it possible to launch iceberg towing in practice (Figure 10).

Moving water physically through towing icebergs is receiving attention amid growing water scarcity but the practice remains in infancy.

Supported by modern science and technology, it appears that towing an iceberg from one of the polar regions to a warmer climate across the ocean is possible. The technical feasibility of iceberg towing can be broken down into four parts: (1) locating a suitable source and supply; (2) calculating the necessary towing power requirements; (3) accurately

Figure 11 Antarctic ice has the potential to supply water to water-scarce areas (Credit: Nicholas Sloane, Southern Ice Forum).

predicting and accounting for in-transit melt; and (4) estimating the economic feasibility of the entire endeavor (Lewis, 2015).

Not just any iceberg can be towed and harvested. Due to the massive size, weight, and density of an iceberg, there is a great risk of one rolling over while being towed. As such, rectangular icebergs with tabular shapes and horizontal dimensions much larger than the thickness are the most desirable (Lewis, 2015).

Since transportable icebergs are abundant and exist in various sizes and shapes, the selection of icebergs for towing to long distances is feasible via remote sensing techniques (Lane et al., 2002). Primarily found in Antarctica, the tabular icebergs are the biggest in size and the most suitable specimens for iceberg towing (Figure 11). The amount of iceberg water that annually dissolves into the sea is 3,000 km³ close to the world's annual consumption of freshwater (3,300 km³). On a relatively small scale, 0.1 million-ton icebergs have been towed successfully. The minimal size to be suitable for water supply to water-scarce areas turns around 1 million-ton (Spandonide, 2009).

In addition to water supply, it is interesting to note that icebergs have the potential to produce energy (Cohen et al., 1990). A large amount of energy can be obtained through the thermal gradient if the icebergs are transported to lower latitudes. In the case of conventional stations operating with fossil fuels, ice can lower the condensing temperature.

Ballast water

Ballast water, which may be freshwater or saline water, is held in tanks and cargo holds of ships as an essential component to ensure vessel stability, navigation safety, and structural integrity, and allows ships to adjust for changes in vessel weight at ports (Walker, 2016). If the ship is traveling without cargo or has discharged some cargo at one port and is on route to its next port, ballast water may be loaded on board to achieve the required safe operating conditions. In all cases, ballast water needs to be treated before de-ballasting because of environmental regulations brought by the 2004 International Convention for the Control and Management of Ships Ballast Water.

Many different water treatment technologies are available for municipal and industrial applications. However, when applying them without modifications for ballast water treatment, none of these technologies has shown the capability to achieve the treatment level required by ballast water treatment standards (Werschkun et al., 2014).

There are two types of standards for ballast water treatment; referred to as Ballast Water Management (BWM) Convention D-1 Standard; and BWM Convention D-2 Standard. The D-1 standard requires ships to exchange a minimum of 95% their ballast water volume in open

With all ships required to meet specific quality of ballast water since September 2019, ballast water offers an opportunity for use amid logistical, quality, and acceptability challenges.

seas, away from coastal areas (International Maritime Organization, 2019). Ideally, this means at least 200 nautical miles from land and in water at least 200 m deep. By doing this, fewer organisms will survive and so ships will be less likely to introduce potentially harmful species when they release the ballast water. The D-2 standard specifies the maximum amounts of viable organisms allowed to be discharged, including specified indicator microbes harmful to human health. Since September 2017, all ships must conform to at least the D-1 standard and all new ships to the D-2 standard. Since September 2019, all ships are required to fulfil D-2 standard. In addition, all ships must have a ballast water management plan; a ballast water record book; and an International Ballast Water Management Certificate (International Maritime Organization, 2019).

Measures for ballast water treatment can be divided into mechanical-physical and chemical processes. The treatment process primarily involves mechanical separation of larger particles by filters or hydro cyclones. Automatic, self-cleaning filter systems with mesh sizes of about 40 μm are frequently used, leaving smaller organisms in the water. Other physical measures are: (1) application of ultrasound and cavitation, which lead to the mechanical destruction of particles and organisms; (2) high energy techniques, such as heating; or (3) UV irradiation. With the combination of high-performance filters and UV radiation, there are several BWM approved methods available that rely entirely on physical treatment methods to achieve the D-2 standard. While these systems have no potential to cause chemical hazards to humans or the environment, their downsides are high energy consumption and potential performance problems in waters of high turbidity or a high content of dissolved organic matter, which may reduce the penetration of UV light (Werschkun et al., 2014).

Based on the estimates that the world seaborne trade in 2013 amounted to 9.35 billion tons of cargo, the global ballast water discharge in 2013 was around 3.1 billion tons; i.e. 3.1 billion m^3 = 3.1 km^3 (David et al., 2015). This suggests that ballast water accounts for one-third of the mass of cargo associated with the world seaborne trade.

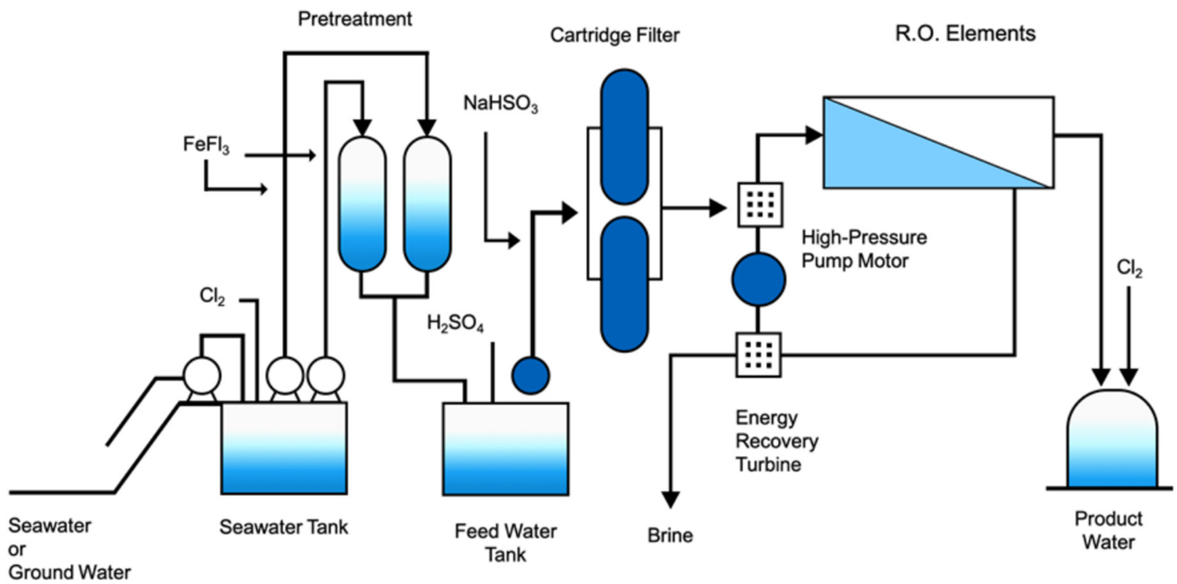


Figure 12 Desalinated water can extend water supplies beyond what is available from the hydrological cycle, providing a climate-independent and steady supply of high-quality water (Credit: Water Globe Consultants).

Desalinated water

Desalination process (Figure 12) removes salt from seawater (salt content between 30,000 and 50,000 mg/L) or brackish groundwater (salt content ranging from 800 to 10,000 mg/L) to render such waters potable (American Water Works Association, 2011). Desalinated water is an important water resource, which extends water supplies beyond what is available from the hydrological cycle, providing a climate-independent and steady supply of high-quality water; the world's oceans contain over 97% of the planet's water resources, providing essentially unlimited raw material for seawater desalination.

With around 16,000 operational desalination plants, daily production of desalinated water stands at 95 million m³ (35 billion m³ annually) of clean water for use in industry, commercial, domestic, tourism, and high-value agriculture. Almost half of the desalination capacity (44%) is in the still-growing Middle East market, but other regions are growing even faster, notably Asia, particularly China, the United States, and Latin America (Jones et al., 2019).

Desalination technologies to produce potable water are divided into two categories – membrane-based and thermal evaporation-based. Over the last decade, Seawater Reverse Osmosis (SWRO), the most prevalent membrane-based technology, has become the method of choice for desalination worldwide due to its relatively lower energy use and cost of water production. After 2015, even most Middle Eastern countries stopped or drastically reduced the construction of new thermal desalination plants (IDA, 2019).

Over the past decade, seawater desalination has experienced an accelerated growth driven by advances in membrane technology and material science. Recent technological advancements such as pressure-exchanger based energy recovery systems, higher efficiency reverse osmosis (RO) membrane elements, nanostructured RO membranes, innovative membrane vessel configurations, and high-recovery RO systems, are projected to further decrease the energy needed for desalination and be the backbone for the rapid decrease in the cost of desalinated water. These advances are projected to yield a significant decrease in production costs by 2030.

A steady downward trend of desalination costs coupled with increasing costs of conventional water treatment and water reuse driven by more stringent regulatory requirements are expected to accelerate the current trend of reliance on the ocean as an attractive and competitive water source. These trends are likely to continue and to further establish seawater desalination as a reliable drought-proof alternative for coastal communities worldwide in the next 15 years. While at present, desalination provides approximately 10% of the municipal water supply of the urban coastal centers worldwide, by year 2030 this is expected to reach 25% (World Bank, 2019).

Currently, more than 150 countries use desalination in one form or another to meet sector water demand, supplying over 300 million people with potable water (Mickley, 2018). Despite declining costs, most desalination facilities are in high-income countries (67%), accounting for 71% of the global desalination capacity. Conversely, less than 0.1 % of the capacity occurs in low-income countries (Jones et al., 2019).

A major challenge associated with desalination technologies is the production of high-salinity concentrate, termed 'brine', which if improperly discharged, may impact the aquatic environment in the area of the plant outfall. However, long-term experience worldwide indicates that if properly designed and operated, discharges from seawater desalination plants are environmentally safe and do not result in significant impacts on the marine habitat in the area of the plant discharge (WRA, 2011;

Environmentally acceptable and economically feasible management of brine is the key to long-term sustainability of desalinated water systems.

Mickley and Voutchkov, 2016; World Bank, 2019; IDA, 2019). Brine production estimates from seawater desalination stand at 142 million m^3/day, approximately 50% greater than the volume of desalinated water produced daily (Jones et al., 2019). Brine production volume from desalination plants using brackish water is 6 to 10 times smaller than the volume of produced desalinated water (WHO, 2007; Cotruvo et al., 2010; American Water Works Association, 2011; Mickley, 2018). Research about extracting rare metals from brine is forging ahead involving new technologies: nanoparticle enhanced membranes, biomimetic membranes and forward osmosis can contribute to beneficial extraction of rare metals from the brine. Such technologies are aimed at reducing energy consumption by 20 to 35%, reducing capital costs by 20 to 30%, improving process reliability and flexibility, and greatly reducing the volume of the brine discharge (IDB, 2019).

Non-technical aspects of unconventional water resources

Beyond technologies and technological innovations, the non-technical aspects of unconventional water resources are as critically important because an enabling environment is necessary to support the uptake of these water resource augmentation opportunities in an area or country. The non-technical aspects include governance, policies and institutions, economics and financial feasibility analysis in the context of circular economy, education and capacity building for skilled human resources and community, culture, and gender aspects.

Governance, policies and institutions

Development of effective policies and efficient governance structures are essential to support harnessing the potential of unconventional water resources, with policies and structures being reflective of the regions and countries in which they are situated.

Since water scarcity addresses countries without recognizing political boundaries, it is important to ensure discussion and coordination of national water-related policies and actions with transboundary dialogue and measures in shared basins. This exchange will help identify joint transboundary opportunities and risks and means to share benefits and costs while harnessing the potential of unconventional water resources across political borders. The Convention on the Protection and Use of Transboundary Watercourses and International Lakes (Water Convention) provides a unique global and legal framework for facilitating reasonable and equitable use of transboundary waters, as well as preventing, controlling and reducing transboundary risks.

In the case of rainfall enhancement through cloud seeding, it is important to consider that artificially altered precipitation would affect the distribution and intensity of atmospheric water and precipitation on the downwind side and may have transboundary impacts. Similarly, geo-engineering would modify the hydrological cycle and thus precipitation, even though the focus of geo-engineering is on solar-radiation management and not weather modification (Bala et al., 2008). Currently, there is only one global treaty that addresses weather modification – the 1978 Convention on the Prohibition of Military and Other Hostile Use of Environmental Modification Techniques, which has 78 parties. As its name attests, the treaty addresses only weather modification exercised as a means of warfare. While some nations have domestic laws about weather modification, thus far no applicable global governance regime has been formally proposed for cloud seeding leading to rain enhancement (Martin-Nagle, 2019).

There is a tacit understanding among the practitioners of fog harvesting that this water should not be sold for profit. Given the type and intensity of fog needed for successful fog collection, such systems are often found in mountainous and poor regions of the world and priority is given to the local population in need.

Making unconventional water resource a public policy priority and establishing supportive institutions and action plans are requisites to efficient water management in dry areas.

Considering also the wide range of legal and public policy bodies in the countries where fog occurs, questions regarding ownership (public-private), monitoring, and quotas need to be country-specific with supportive action plans for scaling up fog collection systems. In practice, there is a lack of national water policies and action plans that consider fog water collection as a means of addressing local water shortages in water-scarce areas with abundant fog. In addition, there are institutional challenges that are contributing to the slow uptake of the potential of fog water collection. A major cause of underperforming or failed fog water harvesting projects is weak institutions coupled with limited inter-institutional collaboration that is reflected through largely unclear and overlapping responsibilities (Qadir et al., 2018). To achieve successful implementation of fog water harvesting projects and their sustainability in the future, it is necessary to integrate the local institutions and associated communities as stakeholders to promote their involvement, commitment, and ownership of the fog collection systems.

Although still in infancy in terms of practice, iceberg towing may be subject to issues of complex policies due to law around the Antarctic, but this will depend upon from where the icebergs are harvested. The Antarctic Treaty System defines Antarctica as all land and ice shelves south of 60°S latitude parallel. The treaty was put in place in 1959 for signatures by 12 countries. The issue of the potential use of ice was raised at several meetings of the Consultative Parties of Antarctic Treaty, but ice was eventually not included in the negotiations and not ratified. Currently, icebergs are not included in the 1991 Protocol on Environmental Protection to the Antarctic Treaty and consequently, iceberg exploitation is not subject to the current moratorium (Spandonide, 2009).

Current plans and discussion for iceberg harvesting target icebergs in the open sea north of 60°S. If plans emerge to exploit icebergs within 200 nautical miles from the Antarctic coast, then this would likely create problems between the claimant and non-claimant States (Spandonide, 2009). Another aspect relates to the decline in the area, extent, and volume of sea ice and melting of the Greenland ice sheet attributed to the increased greenhouse effect caused by the increase in carbon dioxide. Such climate change is having a direct impact on the people that live in the Arctic. Moving icebergs from the Arctic to dry areas may be of concern to the 4 million Arctic inhabitants.

There are large gaps between developing and developed countries as well as between low- and high-income countries for the treatment of municipal wastewater. The treatment of wastewater and use and/or disposal in the humid regions of developed countries, such as the eastern part of North America, northern Europe, and Japan are motivated by stringent effluent discharge regulations and public preferences regarding environmental quality. Treated wastewater is also used for irrigation, but this end-use is not substantial in humid areas. The situation is different in the arid and semi-arid areas of developed countries, such as western North America, Australia, parts of the Middle East, and southern Europe, where wastewater after treatment is used primarily for irrigation (Sato et al., 2013).

In developing countries, municipal wastewater treatment is limited, as investments in treatment facilities have not kept pace with exponential population growth and the corollary increases in wastewater volumes. Thus, much of the municipal wastewater is not treated and released to local water bodies, or used by small-scale farmers for irrigation in dry areas with little ability to optimize the volume or quality of the wastewater they receive (Sato et al., 2013). Apart from the lack of supportive policies and unclear institutional arrangements, the public budgets in most developing countries for water recycling and reuse are inadequate. In addition, limited economic analysis, lack of reuse cost-recovery mechanisms, no or little value for treated wastewater, lack of awareness about the potential of water recycling and reuse, and inefficient irrigation and water management schemes are constraints to effective water recycling and reuse practices. Some countries in dry areas such as Jordan, Israel, and Tunisia have employed a range of conventional and unconventional systems and have national standards and regulations in place for water recycling and reuse. The policymakers in these countries consider reuse of water reclaimed from wastewater as an essential aspect of strategic planning and management of water resources.

In the context of desalination, its raw material source (the ocean) is practically limitless. Desalination is thus drought proof, and it is a good way to deal with drought related climate change risks. It also provides a solid response to exogenous risks such as dependency on other countries for water supply. Singapore, for example, opted for large-scale desalination to reduce its dependence on increasingly expensive imported water from Malaysia. The stable, efficient supplies of urban and industrial water that desalination provides can help governments manage a range of economic, social, and political risks (World Bank, 2019). As water scarcity grows and with advances in desalination technology and reductions in production cost, policy makers around the world may consider action plans supporting desalination in narrowing the gap between water supply and demand in future years.

Governance of offshore freshwater aquifers would involve at least five governance regimes: the UN Convention on the Law of the Sea, customary principles of international water law, the laws and practices that have been developed for offshore oil and gas development, the Convention on Biological Diversity, and the UNEP Regional Seas Programme (Martin-Nagle, 2016; Martin-Nagle, 2020). It is likely that offshore freshwater could be viewed as a mineral or hydrocarbon resource with countries claiming freshwater rights within 200 nautical miles of their coastlines. This could present issues in regions such as the South China Sea (Burgess, 2003).

The International Convention for the Control and Management of Ships' Ballast Water and Sediments, commonly referred to as the Ballast Water Management Convention or BWM Convention, was developed in 2004 as a treaty adopted by the International Maritime Organization (IMO) in order to help prevent the spread of potentially harmful aquatic organisms and pathogens in ships' ballast water. As of September 2017, the treaty has been ratified by more than 60 countries, representing more than 70% of world merchant shipping tonnage. The BWM Convention provides a set of management tools through which the ballast water in the maritime industry can be regulated. At its core are two different protective management regimes with a sequential implementation: BWM Convention D-1 Standard, and BWM Convention D-2 Standard. In order to ensure uniform implementation of the convention, a set of regulatory and technical guidelines were needed, which the IMO developed together with the representatives of the UN Member States, industry, and other relevant organizations (Werschkun et al., 2014).

All ships need to have a ballast water management system (BWMS) on board, and the treatment needs to be as per IMO standards. Compliance with the BWM Convention also requires that the ballast water discharged by ships with a certified BWMS, when tested during routine operations, must meet those allowable ballast water discharge standards. The market for BWMS for ships can be regulation driven depending on how strictly the regulations are enforced and monitored. If BW regulators do not impose strict quality criteria in BWMS markets from the beginning, poor quality can be expected to force out good quality. If that were to happen, BWMS markets would not develop in a way that would allow them to play the critical roles they need to play for ballast water regulations to succeed. If ship owners could be confident that purchasing and installing a certified BWMS would allow their ships to comply with ballast water discharge regulations, quality uncertainty would not be a problem in BWMS markets (King, 2016).

Economic and financial aspects

Although economic valuation of unconventional water resources is complex, it remains an important aspect to guide policymakers and investors to make informed decisions. The valuation of the benefits of action or, alternatively, valuation of the costs of no action is necessary to justify suitable investments in harnessing the potential of unconventional water resources (Hernández-Sancho et al., 2015a).

The perceived high costs of technology for using unconventional water resources without undertaking comprehensive economic analyses and innovative financing mechanisms restrict developing such water resources and scaling up their use (Hanjra et al., 2015). Such economic analyses do not consider the alternate water supply options such as tankers or water transportation from wells from far distances including the costs in the form of women's time, labor, and poor health.

With the aim at eliminating or minimizing waste and recycling and reusing products, materials, and resources, circular economy is a path forward towards harnessing the potential of unconventional water resources. For example, brine generated from desalination plants can be used as a source of valuable minerals, such as calcium, magnesium and sodium chloride. Rare-earth elements can also be extracted from brine including lithium, strontium, thorium and rubidium (IDA, 2019). Recent stresses in the global market of rare-earth elements have brought the availability and supply of rare metals to the forefront of the sustainability debate and research agenda. These metals are used to fabricate critical components of numerous products, including airplanes, automobiles, smart phones, and biomedical

Economics of action vs inaction is needed to overcome the perception of high costs of unconventional water resources without undertaking comprehensive analyses and the cost of alternate water supply options.

devices. There is a growing realization that the development and deployment of clean energy technologies and sustainable products, processes and manufacturing industries will also require large amounts of rare metals and valuable elements (IDA, 2019). In such a scenario, recovery of precious metals from brine would offer an additional economic opportunity while it is ensured that the post-recovery brine would be managed in environmentally acceptable protocols.

In specific situations, the policymakers can make evidence-based decisions if more than one type of unconventional water resources could be available to a specific water-scarce community/area. For example, the communities already using desalination technology can also compare the costs of using offshore freshwater. The desalination costs, once more than $ 5.0 per m³, have dropped to around $ 0.5-0.6 per m³ in recent years due to technology refinement and drop in energy costs (World Bank, 2019; IDB, 2019). In some instances, offshore freshwater aquifers are over-pressured and pumping costs may be minimal, and the economics of offshore water generally suggest a gradual decrease in drilling costs. Within desalinated water options, the cost of desalinating brackish water is significantly less than desalinating seawater, but it depends on the accessibility to brackish water and brine disposal options (Karagiannis and Soldatos, 2008). The city of Cape May in New Jersey is currently desalinating brackish water at the coastline, and the economics suggest that this is cost-effective.

Another aspect of economic growth using offshore freshwater is in the petroleum industry. Petroleum companies are considering utilizing freshwater to enhance oil production as part of an enhanced oil recovery strategy. Water flooding with freshwater has been shown to increase oil production (Zhang and Morrow, 2007; Person et al., 2017). Development of offshore groundwater for enhanced oil recovery would provide support for the economics of offshore freshwater development. British Petroleum is currently evaluating the economics of low-salinity water flooding on its Claire Ridge oil platform in the North Sea.

In case of addressing local water shortages, site-specific water collection systems, such as fog water harvesting, need to consider the cost of water collection from fog and its comparison with the cost of other sources of water available to the community. For example, the price charged for water in six cities of the Atacama Desert in northern Chile in 2011 ranged from $1.96 to $3.06 per m³ (LeBoeuf and Jara, 2014) while in Eritrea, water price was between $1.7 and $3.3 per m³ in the areas with good potential of fog water collection (Fessehaye et al., 2014). The costs of fog water collection show large variation ($1.4 per m³ to $16.6 per m³) due to variations in the material and labor costs, presence or absence of subsidies, and the efficiency of fog collection systems in different locations (Qadir et al., 2018).

In some cases, it is difficult to compare the costs of some water resources, such as fog water and desalinated water, because of the differences in scale of the two technologies. Additionally, fog harvesting technologies are resource-intense during the installation phase, but then require very little maintenance or additional resources, while systems like desalination and wastewater treatment require continuous input of energy, chemicals, and labor. Another aspect of fog water collection system is that such system can only be local and small-scale to provide the local population essential supply of potable water, so they remain on their land. As water scarcity could be a potential driver of forced migration such as in the case of drought-related displacement, connecting entire communities to fog water collection system could ensure their water security and through that potentially reduce forced migration. Such benefits to the local communities are difficult to monetize.

The economic benefits of precipitation enhancement arise from the value of the increased water reaching the ground. That water either feeds directly to agricultural crops or more likely leads to increased runoff into regional hydrological system. However, a major challenge for precipitation enhancement is that the physical processes extend across an extremely large range of spatial and temporal scales, at the same time making this technology highly valuable for irrigation. Terblanche et al. (2005) and Shippey et al. (2004) estimated the benefit-cost ratio of additional rainfall in South Africa and observed that rainfall enhancement supported by efficient ways to deliver seeding material could be more favorable than other options to address water stress in the country. In estimating the economics of cloud seeding, it is necessary to account for the benefits of additional water over the seeded area and for the total costs of a continuing operational project. Those costs include actions needed to obviate any potential environmental risks (WMO, 2018). Assessments of projects around the world on the costs of rain enhancement suggest the cost could be even less than \$0.10 per m³ (Terblanche et al., 2003).

The projected costs of iceberg harvesting can be broken down into four components: (1) technological innovation; (2) iceberg identification and retrieval; (3) transportation; and (4) arrival site processing and distribution (Lewis, 2015). These costs must be competitive with those of alternative freshwater supplies. Although, some recent financial analysis of the estimated yearly amortized capital investment necessary to run an iceberg towing and harvesting operation has not been done, estimates undertaken in the 1970s suggest that an iceberg could be delivered at a cost of approximately \$20 per acre-foot (1 acre-foot = 1,233 m³) or \$0.016 per m³ (Lewis, 2015). Compared to the estimates for other options such as long-distance inter-basin water transfer or desalination, iceberg harvesting would be a relative bargain (Lewis, 2015).

The incentive to treat and use treated wastewater lies in the cost recovery of the treatment process. The principle of cost recovery is rarely met in water reuse projects. The first step to improve the application of this economic principle is to identify the barriers that prevent policy makers establishing higher water reuse tariffs. Three assumptions are needed to employ a pertinent pricing strategy: (1) the political climate accepts the 'polluter pays' principle; (2) the water users are likely to be responsive to price changes; and (3) there are no critical thresholds being approached such as a level of extraction where irreparable damage is likely to occur (Hernández-Sancho et al, 2015b). In general, the principle of polluter pays is accepted by urban and industrial users accustomed to the charges for sanitation services. However, this principle is not largely accepted by the farmers. Potential responsiveness to price is difficult to assess given the variety of users of regenerated water. In this field, the response of farmers to changes in water tariffs is conditioned by aspects such as the existence of water rights, the productivity of the crops, or the existence of water markets. Therefore, application of a pricing policy should be based on a case-by-case situation. It is essential to understand the possible interferences, positive and negative, with other farming policies. In general, to take measures in relation to water price, which includes regenerated water, it is vital to analyze demand elasticity for each use. Otherwise, the measures adopted may not lead to the expected results (World Bank, 2019).

Environmental and ecosystem aspects

When considering the use of water resources, which are not common in the prevailing paradigm of water resources management, it is essential to consider the environmental tradeoffs of using such water resources including potential transboundary impacts resulting out of their use. While desalination provides a valuable and reliable water resource, it also generates brine with salinity higher than the ambient saline water source, which may pose an environmental challenge if not managed properly. Substantial efforts, innovation and research are currently invested into: (1) reduction in the volume of brine being produced (i.e., in the increase of the efficiency of the desalination process); and (2) treatment and/or use of the brine that is produced in an economically viable and environmentally friendly way (Jones et al., 2019). In recent years, the desalination industry has developed several brine concentration and mineral extraction technologies, which enable the manufacture of commercially valuable products from brine (IDA, 2019). Extracting minerals from seawater is a more environmentally friendly enterprise than terrestrial mining. Moreover, seawater extraction does not require freshwater for processing. In addition, new brine concentration technologies may result in significant reduction or complete elimination of brine discharge to the sea. Over the past 5 years, many countries with large desalination plants such as the Kingdom of Saudi Arabia, Spain, and Israel have initiated the implementation of comprehensive programs for green desalination, which aim to reduce both the amount and types of chemicals used in the production of desalinated water. These programs ultimately aim to convert all existing desalination facilities to chemical-free plants by implementing the latest advances of desalination technology and science (IDA, 2019).

If iceberg harvesting were to prove successful, the environmental and societal benefits would be extensive (Lewis, 2015). For example, if there had been an iceberg conveniently parked off the Atlantic coast, the effects of the chemical pollution of West Virginia's water supply in late 2013 could have been significantly mitigated (Kroh, 2014). On the other hand, there could also be adverse environmental effects of iceberg towing. The most significant risks of adverse environmental impacts appear to be at the point of destination. Weeks and Campbell (1973) anticipated several temperature-induced effects such as increased fogging and rain from the thermal plume condensation coming from a massive iceberg parked just off a coastal region. They further posited that the effect on local ecosystems and tides might be harmful (Lewis, 2015). At present, no study has adequately considered the primary and secondary impacts that iceberg harvesting would have once the iceberg reaches its onshore destination and then distributed domestically.

Fog water collection is an environmentally friendly intervention that does not rely on energy consumption. There are no negative environmental effects of fog water harvesting in surrounding areas as atmospheric water represents 0.001% of total water in the world and 0.04% of freshwater (Graham et al., 2010) and the amount of water that could be harvested through fog collection remains negligible. Similarly, no negative effects of fog water collection have been reported on local vegetation and insects and the dependent ecosystems.

Offshore freshwater is a non-renewable resource, but the lure of the immense volumes lurking in the sea-beds will eventually overcome hesitancy about the unsustainability of development. Large scale offshore freshwater development has not taken place at any field sites to date. Where offshore aquifers are connected to onshore aquifers, long-term pumping of offshore freshwater could result in reversals in groundwater flow directions offshore that could impact benthic community health. Further, mathematical models indicate the potential for onshore land subsidence and seawater intrusion from extraction of offshore groundwater. Thus, social and economic considerations must be weighed in making development decisions related to developing offshore freshwater (Yu and Michael, 2019). In addition, development of offshore freshwater will impact the marine environment in ways that are like development of offshore hydrocarbons, including damage to flora and fauna in the surrounding seabed and water column (Cordes et al., 2016; Martin-Nagle, 2020). Despite the risks during times of drought, utilization of offshore freshwater by coastal megacities may represent an important water source for coastal residents.

Treating and using wastewater would reduce the discharge of untreated wastewater into the environment (so reducing water pollution and the contamination of drinking water supplies), and would improve the socioeconomic situation of farmers, and thus their health and that of their families. Depending upon the levels of contaminants present, continued and uncontrolled use of untreated wastewater as an irrigation source could result in groundwater contamination through the movement of high concentrations of a wide range of chemical pollutants (Ensink et al., 2002). This is particularly true in the case of wastewater that contains untreated industrial effluent. Such wastewater use may also lead to a gradual build-up of specific ions such as sodium and a range of metals and metalloids in the soil solution and on the soil's cation exchange sites. This may lead to potentially harmful metals and metalloids reaching phytotoxic levels. The accumulation of potentially toxic substances in crops and vegetables can enter the food chain, affecting human and animal health. For example, leafy vegetables irrigated with untreated wastewater containing metals and metalloids can accumulate higher levels of certain metals, such as cadmium, than non-leafy species (Qadir et al., 2000). Excessive exposure to this metal has been associated with various illnesses in people, including gastroenteritis, renal tubular dysfunction, hypertension, cardiovascular disease, pulmonary emphysema, cancer, and osteoporosis. Further, it has been observed that farmers using untreated wastewater for irrigation demonstrate a higher prevalence of hookworm and roundworm infections than farmers using freshwater for irrigation. Hookworm infections occur when larvae, added to the soil through wastewater use, penetrate the skin of farmers working barefoot (Van der Hoek et al., 2002).

Efficient farm-level salt and water management are essential in the case of using agricultural drainage water for irrigation to minimize salt

A bottom-up approach where stakeholders vet major water resources issues, goals, objectives and potential solutions and community involvement is ensured is the way forward to offset the environmental tradeoffs of unconventional water resources.

build-up in the root zone and the size and cost of regional drainage efforts. Historically the focus has been on the expansion of irrigated area without paying much attention to the management of salts it generated. The planners of most irrigation schemes considered water quantity and ignored the fact that water quality inevitably degrades along the sequence of subsequent water uses. They did not account sufficiently for the downstream effects of excessive irrigation based on the anticipation that the surface runoff or deep percolation from one farm would be beneficial to other farms in the downstream areas (Wichelns and Qadir, 2015). Consequently, the irrigating farmers did not have impetus to use water efficiently to minimize addition of salts to surface streams and groundwater. In fact, the practice 'irrigate now, manage salts later' has continued without paying much attention to salt and drainage management until salt build-up in irrigated lands reached alarming levels.

There are 'bright spots' of managing salt and water effectively at the watershed and basin scales. For example, One Water One Watershed (OWOW) is an innovative planning process for the Santa Ana River Watershed that integrates water resources management with various disciplines such as land use planning, flood control, and natural resource management. The Santa Ana River Watershed is defined by its geopolitical boundary that includes the largest river in Southern California and one of the fastest growing populations in the State (Santa Ana River Watershed, 2014). A range of stakeholders was involved in developing the plan concluded that planning and working together and using shared data and tools would allow them to achieve the mission of OWOW. The goals of OWOW are: a watershed that is sustainable, drought-proofed and salt-balanced by 2035 where water resources are protected and water is used efficiently; a watershed that supports economic prosperity and environmental viability; a watershed with diminished carbon emissions and resilient to climate change; a watershed free of environmental injustices; a watershed where the natural hydrology is protected, restored and enhanced; and instilled water ethic within institutions and people that will make efficient use of water a California way of life. With funding from local, state and federal governments, OWOW is stemmed from a bottom-up approach where stakeholders vetted major water resource issues, concerns, problems, goals, objectives and potential solutions. They also developed a deeper understanding of local issues and generated greater buy-in and support.

Education and capacity building needs

Scaling up the use of unconventional water resources needs awareness and capacity building initiatives as per the resource. For example, desalination provides a bulk water supply source. Although international expertise related to desalination exists, but at a local level, utilities generally need to build capacity for desalination as the technology is complex and experts are required for the conceptualization, planning and implementation of desalination facilities in developing countries to make desalination being more accessible rather than relying on imported and expensive expertise.

In the case of community-based unconventional water resources, such as micro-catchment rainwater harvesting and fog water collection, education and capacity building of the local communities is the key to the success of these water resources. For example, although fog collection systems are based on relatively simple designs and their operation and maintenance are minimal and easy to manage, their sustainability depends on sound professional support during the planning, financing, implementing, and regulatory stages of a project. This is important as fog collection systems are community-based, and community members are usually not fully aware of the basics or specific operational aspects unless their capacity to manage these systems independently or with minimal support is developed (Fessehaye et al., 2014). As an example of effective capacity building and progressive handover, after ten years of fog collection in Tojquia, Guatemala,

Skilled human resources in developing countries are limited to address the complexity of assessing and utilizing some unconventional water resources.

the community created a water committee elected by the community members. The committee is responsible for the operation and maintenance of the fog collectors and communication with the community and external organizations involved in the project (Schemenauer et al., 2016). This knowledge transfer between stakeholders is crucial, and it applies to both male and female segments of the community as all are usually involved in fog collection and system's management. Therefore, it is appropriate to run capacity needs assessment of the local community and local institutions followed by need-based capacity development (Qadir et al., 2018).

In Morocco, organizing water-education and capacity building for the local population was found to be an important and structuring element in the fog water project in Dar Si Hmad, Morocco, where an "Oasis School" was created to offer fog water specific education to the associated community resulting in fog water use for the school gardens. After 3 years, the school presents a green outlook with some fruit and vegetable species while previously there were just dirt school yards (Bargach et al., 2015).

While dealing with unconventional water resources at the field scale, such as using municipal wastewater and agricultural drainage water for irrigation, there is a lack of professionals in developing countries that can address the complex and interrelated issues of health, irrigation, drainage, and salt management in a sustainable manner. Even though many scientists deal with such topics, they lack skills in using innovative options and tools, such as transient-state models (Oster et al., 2012), to manage drainage and salts, metals and other undesirable constituents. In an era of precision agriculture, salt-leaching practices to control soil and water salinity still rely largely on well-worn approaches, such as conventional methods of estimating salinity levels in water and soil. At the regional scale, application of regional scale hydrology and ecology models, although imperfect, are a valuable resource for evaluating the possible environmental consequences of alternative methods of water management (Schoups et al., 2005).

Beyond community and field scale, other unconventional water resources need more outreach and awareness activities through research projects to share the data, technology, and knowledge to wider scientific community addressing unconventional water resources elsewhere in the world. For example, the MARCAN project investigating the role of offshore groundwater in the geomorphic evolution of continental margins with a focus on offshore water in Malta and New Zealand (Micallef et al., 2018). Similarly, another project is investigating the status of offshore freshwater in Bangladesh and New Jersey.

Community participation and gender mainstreaming

Community participation is an important aspect of promoting the use of some unconventional water resources. In the case of fog water collection systems, a key project launched in

1987 in El Tofo, Chungogo, Chile stopped around 2007 due to the lack of community support; the generational turn-over; and the political interference that prevented an upgrade in the project fog water collection units. Community participation is important for maintenance of the nets for fog water harvesting. The ones supported by the community, such as by a school (Ethiopia) or by local institution and community (Morocco and Peru) continued functioning (Bargach et al., 2015).

Micro-catchment rainwater harvesting systems are advantageous because they are simple to design and cheap to install. They can also be adapted for use on almost any kind of slope, including slight slopes on almost level plains. Local communities can be involved and easily trained to implement such systems. With little conveyance losses, these systems provide higher levels of runoff efficiency than macro-catchment water harvesting systems (Qadir, et al. 2007).

Community participation typically forms part of environmental impact assessments (WHO, 2007; Voutchkov, 2012; IDA, 2019). While communities are principally concerned with water security and the cost of additional water supplies, acceptability of the source water also plays a part where communities need to be engaged to reach an agreement prior to implementation of the water provision project. For example, community acceptance is crucial for the successful implementation of desalinated water as part of the water supply mix (Cotruvo et al., 2010; World Bank, 2019; IDB, 2019).

Since fog water collection systems are implemented within or near communities, they eliminate or substantially decrease the need to travel far distances for water (Dodson and

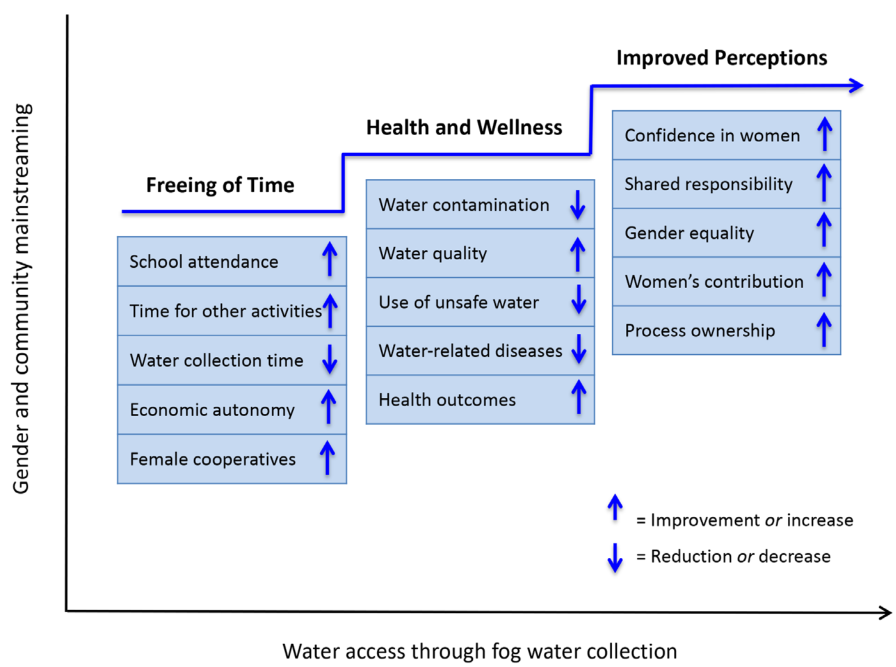


Figure 13 Key elements of gender through fog water collection projects showcasing a range of positive outcomes for the female segment of the communities when moving from time-consuming and laborious water collection approaches to using fog water collection systems (Lucier and Qadir, 2018; Open access under the terms and conditions of the Creative Commons Attribution).

Bargach, 2015) and reflect positive physical and social outcomes for women and girls, such as: (1) A drastic decrease in the time previously spent on water collection from far distances, resulting in the freeing of time for domestic and educational pursuits in fog collection areas; an increase in school attendance by girls; and the establishment of female cooperatives to promote home-made products resulting in economic independence (Fessehaye et al., 2014; Dodson and Bargach, 2015; Bargach et al., 2016); (2) improved health outcomes through immediate decrease in the use of contaminated water collected previously from polluted water sources and access to, and use of, better quality water collected from fog leading to a decrease in water-borne diseases and improvement in health and wellness; and (3) improved perceptions of self and position within the community through self-confidence, gender equality, recognition of women's contribution and shared ownership of the female segment of the community in fog collection systems (Figure 13; Lucier and Qadir, 2018).

Gender mainstreaming is a key factor in the success and sustainability of community-based projects on unconventional water resources.

In case of wastewater, inclusive and gender-sensitive water management policies also support safe and productive use of wastewater. Where wastewater treatment is insufficient and wastewater irrigation common, safety measures can be implemented at critical control points along the food chain (from 'farm to fork') as gender roles can change from the farm level to wholesale, and to retail (Drechsel et al., 2013). Where risk awareness is low and not easy to develop, it is important to determine how best to motivate and trigger a behavior change and encourage the adoption of gender-sensitive risk mitigation measures. In many cultures, women not only carry the main responsibility for hygiene and health but are also in charge of greywater or wastewater use for irrigation. This connection offers significant potential for innovative training approaches to improve the social acceptance of safe wastewater use.

Aside from increasing reliability and assurance of supply to the benefit of the community, other unconventional water resources do not have specific gender aspects.

Key barriers and response options

Despite demonstrated benefits to augment water resource in dry areas, the potential of most unconventional water resources is vastly under-explored due to certain barriers. For example, in the case of potable water supplies via fog water collection, culturally there is apprehension regarding using fog as a source of water, requiring repeated consultations with the community to address concerns that the water quality is safe, involving the religious authorities in certain cultures for the benediction of the water. There is also difficulty in securing accessibility and use of the land on which the fog collectors are to be built. In certain cases, individuals and families have destroyed the fog harvesting units or prevented other community members from accessing them because of land tenure issues. Further, bringing heavy material to install fog collection units is a demanding logistical process that needs to be seriously considered. Opening possibilities for volunteers and soliciting local and international support can be one of the solutions to tackle this hurdle.

An important aspect in cloud seeding and all forms of weather modifications, even to some extent fog harvesting, is the potential transboundary issue, even if the boundaries are within domestic borders. Weather modification taking place at higher levels of the atmosphere has the potential to impact broader geographical areas. Inducing premature precipitation through cloud-seeding and other manipulation of clouds could have profound and intense consequences, but the effect on the atmosphere would be short-lived. On the other hand, geo-engineering could leave lasting effects on weather patterns and the hydrological cycle and may have the potential to impact transboundary water resources distribution (Bala et al., 2008).

In the absence of any guidance on governance of high-impact weather modification, policymakers desiring to manage these techniques and prevent catastrophic changes may begin with some well-defined principles of international water law (Salman, 2011). Harvesting rain or fog that would have naturally passed into another state could be viewed as a new version of the rule of capture, and collaborative arrangements like unitization agreements may eventually evolve to apportion a shared resource equitably and reasonably. In another analogy to international water law, the tension between upstream and downstream riparian countries or areas could arise for atmospheric flows, and the principle of equitable and reasonable utilization may find a new application (Martin-Nagle, 2019). Indeed, equitable and reasonable utilization of prematurely induced precipitation may take the form of benefit sharing, with states agreeing to share the benefits of the altered precipitation patterns. However, given the potential for harm, the principle of no significant harm must become primary, and the precautionary principle should be the guiding light for governance of weather modification. While the polluter pays principle may have limited applicability in weather modification, its premise that an actor should compensate non-actors for damage could easily apply to damage done by artificially induced floods, mudslides, landslides and other types of unnatural disasters (Martin-Nagle, 2019).

There are challenges to the sustainability of micro-catchment rainwater harvesting systems as they depend on limited and uncertain rainfall. Other disadvantages are that (1) the catchment area is most efficient when kept free from vegetation, which may require high labor inputs; (2) the system may be damaged during heavy rainstorms and need regular maintenance; (3) the catchment uses land which could otherwise be used to grow crops, if sufficient water is available, except in the case of steep slopes, and (4) the systems allow only low crop densities and low yields in comparison with conventional irrigation systems (Prinz, 1996).

In addition to these substantive principles, procedural principles such as data sharing, cooperation and advance notice should be mandatory, although advance notice may be unnecessary if cooperation is embraced, practiced and enforced. Last but certainly not least, environmental protection must be addressed, and environmental impact assessments should accompany any proposal for all but the slightest weather modification, despite the uncertainty that may accompany any predictions (Martin-Nagle, 2019). All these substantive and procedural principles would apply to any type of weather modification with a potential for transboundary impact. The differences would arise in the type of joint committee and the extent of sovereign rights. For example, fog harvesting will have only local effects, so joint committees addressing weather modification could rely on representatives from the locally affected environments, and limitations on sovereign could be agreed by the parties. However, cloud-seeding and manipulation of atmospheric rivers could have both local and regional impacts, and states should be more inclusive in selecting the representatives to serve on the joint committee (Martin-Nagle, 2019).

One of the key barriers to offshore freshwater development is drilling and pipeline costs. It is speculated that once one group has successfully (and economically) developed offshore freshwater, others will follow. One important initiative to move offshore freshwater development forward is the Integrated Ocean Drilling Program (IODP) to conduct pilot drilling studies with confirmed offshore freshwater.

Desalinated water is an unconventional water resource, which has come a long way to overcome its initial barriers, and now is on a path to where it is likely to be the most acceptable alternative water supply source in the majority of arid and semi-arid regions in the world. The advancements in the reverse osmosis desalination technology are close in dynamics to that of computer technology. While conventional technologies, such as sedimentation and filtration have seen modest advancement since their initial use for potable water treatment several centuries ago, new but more efficient seawater desalination membranes and membrane technologies, and equipment improvements are released every few years. Like computers, the reverse osmosis membranes of today are many times smaller, more productive and cheaper than the first working prototypes (World Bank, 2019). Although, no major technology breakthroughs are expected to drastically reduce the cost of seawater desalination in the coming years, the steady reduction of desalinated water production costs coupled with increasing costs of water treatment driven by more stringent regulatory requirements, are expected to accelerate the reliance on the ocean as an attractive and competitive water source by 2030. These technology advances are expected to ascertain the position of seawater reverse osmosis as a viable and cost-competitive process for potable water production and to reduce the cost of freshwater production from seawater by 25% by 2022 and by up to 60% by the year 2030 (IDB, 2019). The rate of adoption of desalination in coastal urban centers worldwide will depend on the magnitude of water stress to which they are exposed to and availability and cost of the conventional water resources.

To successfully implement water reuse projects, three key aspects have been identified. First, the increase in the quantity of wastewater treated motivated by new regulations; Second, technical improvements in wastewater treatment systems tailored to end-user needs at affordable costs; Third, the institutional and societal context focus on water reuse regulations (Winpenny et al., 2010; Hernández-Sancho and Molinos-Senante., 2015). Private as well as public water companies need to explore opportunities to valorize the reuse of water and hence expand their variety of uses. This shift needs to be accompanied by analyzing demand and market opportunities as well as identifying feasible business models. Against this background, a challenge to be addressed is to explore financial and economic instruments to promote water reuse and make this an attractive option on water markets and beyond. In doing so, information about current costs of water reuse projects, tariffs and subsidy arrangements as well as the overall acceptance and issues of awareness raising should be investigated. Some recommendations to mainstream this unconventional water resource include: (1) supportive water policies, (2) supportive technical environment and innovations, (3) awareness raising measures, and (4) feasible business models by the design of an innovative tool, the Advanced Decision Support System, ADSS (Hernández-Sancho et al., 2015a). The output of the ADSS is an environmental and cost-effective assessment to evaluate each activity and the whole urban water cycle as well as recommendations for the best practices to improve the efficiency of the water management systems. The ADSS can compare different technological solutions and show the benefit of water and wastewater treatment against the no-treatment scenario, i.e. the cost of action vs. the cost of no action in wastewater collection, treatment, and water reuse systems (Hernández-Sancho et al., 2015a).

The way forward – Promoting the enabling environment

Climate change may impact livelihoods and lead to conflicts within and between countries by impacting water resources variability and quantity. The world at large is addressing both risks in the 2030 Sustainable Development Agenda with specific goals – SDG 6 on water and water-related targets embedded in other SDGs. Water and climate change are interconnected as climate change increases the likelihood of extreme droughts in dry areas, which are often located in transboundary basins. Despite such interconnectivity, water crisis and climate change are at times addressed in silos, which turn into a major roadblock in the journey to achieve water-related sustainable development amid changing climate in the SDG era and beyond. This is particularly important in arid and semi-arid areas. Harnessing the potential of unconventional water resources and integrating it into water resources management strategies and plans at the transboundary, national and local levels can go beyond narrowing the water demand-supply gap by developing resilience of water-scarce communities against climate change by diversifying water supply resources.

Integrating unconventional water resources into water resources management strategies in dry areas can develop resilience of water-scarce communities against climate change.

While the water sector faces diverse challenges, it is making significant progress towards cost-effective and sustainable water management solutions, which are expected to transform water management and gradually shift its reliance from conventional to unconventional water resources in water-scarce areas. Another encouraging trend is seen in water professionals and policymakers considering the critical role of unconventional water resources in building a water-secure future where water is recognized and treated as a precious resource and as a cornerstone of the circular economy. While recognition is growing in high-income and upper-middle-income countries, this awareness needs to be replicated in low-income and lower-middle-income countries, particularly those where water scarcity and water quality deterioration are prevalent. Such a trend is essentially needed at a time when most countries around

Given limited consolidated information and data, quantification on how far unconventional water resources can narrow water demand-supply gap at different scales remains a challenge.

the world are not on track in addressing SDG 6 and water-related targets in other SDGs. There is an urgent need to enter into a new era of water management where the barriers to efficient water management gradually fade and where water in all of its forms is closely monitored, digitized, accounted for, and reused rather than being considered just a simple supply source or a waste product released into the environment without sufficient treatment, as in the case of untreated wastewater.

Traditionally, water utilities have managed water supply and treatment of wastewater, with a focus on minimizing the impact on the environment by removing nutrients and using the resources from waste streams in a beneficial manner. In order to adapt to the challenges faced in the next 10 to 15 years, water utilities need to develop a diversified portfolio of water supply in which unconventional water resources have a significant share in water-scarce areas.

Some unconventional water resources need further research. For example, the scientific status of weather modification, while steadily improving, still reflects limitations in the detailed understanding of cloud dynamics and microphysics, and precipitation formation, as well as limitations in accurate precipitation measurements. Governments and scientific institutions need to substantially increase their efforts in basic physics and chemistry research related to weather modification for reclaiming water from the atmosphere. Further testing and evaluation of physical concepts and seeding strategies are critically important. The acceptance of weather modification can only be improved by increasing the number of well executed experiments and building the basis for scientific results that are consistent and positive.

Some unknowns and research questions about unconventional water resources need to be addressed in a journey to harnessing the potential of such water resources.

As global water crises loom and achievement of the SDG 6 and water-related targets in other SDGs grows doubtful, the world must begin to analyze and consider utilization of unconventional water resources individually and collectively. The disparate forms of unconventional water resources have resulted in policies and governance structures that can be inconsistent and in scientific analyses and data that can make cogent comparisons difficult. Thus, unsustainable and conflicting policies may almost certainly result, which would be detrimental to the efforts to incorporate unconventional water resources in the overall water management planning and implementation initiatives. Effective policies and efficient governance structures are essential to support harnessing the potential of unconventional water resources, and such policies and structures may vary across regions and countries. They also need to be coordinated and agreed in transboundary basins for ensuring the most efficient use of unconventional water resources as well as preventing and reducing any potential transboundary impacts out of such use.

International collaboration opportunities across regions and countries in harnessing the potential of unconventional water resources are crucial. Given the importance of unconventional water resources and need for financial resources to harness their potential, the private sector’s involvement needs to be encouraged in investing in projects on unconventional water resources. Beyond private sector, there is a need for a platform to connect the experts, practitioners, young professionals, media, community, and policymakers to exchange literature, ideas, presentations, and capacity development material as well as information on key events and sessions at workshops and conferences addressing one or more unconventional water resources. Such activities are expected to trigger collaboration and implementation of the related activities on the ground. Governments and other agencies that are open to explore alternative water resources should invest in relevant education, training and capacity building through local, national, and international opportunities. Social media can play a major role in promoting the importance of unconventional water resources in arid and semi-arid regions. The next stages in the development of these resources may benefit from a multi-disciplinary effort that would provide insights and guidance on productive and sustainable use of unconventional water resources.

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