CZECH UNIVERSITY OF LIFE SCIENCES PRAGUE

Faculty of Tropical AgriSciences

Water harvest technologies for arid and semi-arid areas

BACHELOR’S THESIS

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Declaration

I hereby declare that I have done this thesis entitled “Water havest technologies for arid and semi-arid areas” independently, all texts in this thesis are original, and all the sources have been quoted and acknowledged by means of complete references and according to Citation rules of the FTA.

In Prague 2024

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Nicola Siviglia

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Abstract

This thesis thoroughly examines water harvest technologies as sustainable solutions to mitigate water scarcity in arid and semi-arid regions. Beginning with an introduction that outlines the urgency of addressing water scarcity and briefly explains basic terms, the thesis delves into the socio-economic and environmental impacts of this pressing issue. Through a systematic exploration of rainwater harvesting, fog collection, and desalination facilities, the thesis presents a range of innovative approaches to augmenting water resources in water-stressed areas. Through a combination of research findings, practical applications, and case studies, the thesis offers valuable insights into the design, implementation, and effectiveness of water harvest technologies. Furthermore, the concluding chapter underscores the significance of integrated water management strategies and provides recommendations for future research and policy interventions. Overall, this thesis contributes to the advancement of knowledge in the field of water resource management and underscores the importance of sustainable practices in addressing water scarcity challenges globally.

Keywords: water harvest, RWH, fog collection, desalination, technologies, arid and semi-arid, water scarcity, resources

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List of the abbreviations used in the thesis

RWH	rainwater harvesting
RO	reverse osmosis
SDGs	Sustainable Development Goals
SFC	Standard Fog Collector
PVC	polyvinyl chloride
MED	Multi-effect distillation
MSF	Multi-stage flash
LFC	Large Fog Collectors
kWh	Kilowatt hours
L	liter
m3/d	cubic metres per day

1. Introduction

Water harvesting is a common practice used to increase water availability for both private and agricultural use (Lasage & Verburg 2015). Globally, water scarcity poses a significant challenge, especially in arid and semi-arid areas where water supplies are naturally scarce (El Kharraz et al. 2012). Almost two billion people live in these regions, making up about one-third of the planet's land area. Many of them struggle daily to get access to clean, consistent water supplies. These regions suffer from a shortage of water, which is made worse by unsustainable water management techniques, population increase, urbanisation, and climate change.

High rates of evaporation, little and irregular precipitation, and frequently restricted access to surface water bodies are characteristics of arid and semi-arid regions. Communities in these environments are often faced with ongoing water shortages that impair agricultural output, endanger livelihoods, and compromise food security. Furthermore, a lack of water exacerbates disputes over available supplies and fuels social and economic inequalities both within and between communities (El Kharraz et al. 2012).

Different water harvest technologies have been created in response to these issues to more effectively and efficiently gather, store, and use the available water resources. These technologies range from modern innovations like fog collection systems and desalination facilities, as well as more traditional methods such as rainwater harvesting. Various technologies have different benefits and drawbacks based on variables including geography, climate, and socioeconomic context.

For instance, rainwater harvesting is the process of gathering and storing precipitation from land surfaces, watersheds, or rooftops for use in industrial, agricultural, or domestic applications later on (Boers & Ben-Asher 1982). This approach includes a wide range of collection methods, from basic cisterns and barrels to sophisticated rooftop harvesting systems. Rainwater harvesting minimises the need for energy-intensive water treatment and distribution procedures by capturing rainwater directly at the point of use. It also helps with erosion control, groundwater replenishment and urban flooding mitigation. In recent years, possible applications of these technologies have increased due to technological breakthroughs. Rainwater harvesting can be integrated into urban infrastructure through creative methods like rain gardens, permeable pavement, and green roofs, which improve water efficiency and urban resilience. Even though used for generations already, this ancient method has been getting more attention recently as a long-term sustainable response to water scarcity, especially in areas with restricted access to centralised water infrastructure. Governments and organisations can encourage the broad adoption of rainwater harvesting techniques, promoting water security and sustainability for future generations, through promotions, education, and policy support.

In comparison to this, fog collection systems represent an innovative method of gathering water; they use the moisture in fog to enhance water supply in dry and semi-arid areas. These systems usually consist of specifically made nets or meshes that are placed in fog prone locations, where the currents of wind carry water droplets, which are then collected and stored for a variety of uses (Fessehaye et al. 2014). One of the main benefits of fog collection technology is its potential to work as a dependable water supply in areas where conventional water sources are hard to come by or very inconsistent. In contrast to precipitation, which can be irregular and unexpected, fog is more common in some coastal and mountainous regions and provides a steady supply of moisture for accumulation (Fessehaye et al. 2014). That is why this method of water collection is especially well-suited for settlements located in isolated or hard-to-reach areas with limited access to clean water. Although the technology is still relatively new, it shows a lot of promise as a cost-effective and environmentally friendly means of alleviating water scarcity. To enable wider adoption, the efficiency, durability, and capacity of fog collection systems are being improved through ongoing research and development efforts. Many countries around the world have already successfully implemented these systems in efforts to improve their living conditions, including Colombia, South Africa, Saudi Arabia, Ethiopia, Israel and the Canary Islands, among others (Qadir et al. 2021).

Water harvest technologies have several obstacles to overcome before they can be widely adopted and implemented, despite their potential benefits. These obstacles include those related to technological feasibility, economic viability, social acceptance, and policy support (Mwenge Kahinda & Taigbenu 2011). Furthermore, the efficiency of these technologies may differ based on regional environmental circumstances and cultural norms, emphasising the necessity for context-specific solutions adjusted to the particular difficulties of each area.

The significance of this study lies in its relevance to both academic and practical applications. Academically, it broadens our understanding of water management techniques in arid and semi-arid areas by shedding light on the advantages and disadvantages of various water harvesting methods. In practical terms, the knowledge gathered from this study can help local communities, water managers, and policymakers to create and implement sustainable water solutions that are suited to particular geographic and socioeconomic circumstances.

2. Aims of the Thesis

Through a comprehensive review and consultation of scientific literature, journals and case studies, this thesis seeks to learn and assess the efficiency and suitability of different water harvest technologies applied and identify key barriers hindering widespread adoption and implementation, while aiming to identify the best practices and potential areas for improvement.

This thesis aspires to contribute to the advancement of sustainable water management practices and the alleviation of water scarcity challenges in arid and semi-arid areas. Unlike previous studies that mainly focus on individual technologies, a more holistic approach is taken, examining multiple water harvesting methods and evaluating their efficiency, suitability, and socio-economic potential.

Ultimately, the goal of this thesis was to summarize scientific information, fill gaps in our current knowledge, and provide valuable insights, and recommendations for the adoption and optimization of water harvest technologies in globally arid and semi-arid regions.

3. Methodology

The thesis was written as a literature review following the manual of the Faculty of Tropical AgriSciences for writing Bachelor’s Thesis and all literature is cited according to rules set by the faculty. First step was the evaluation and consultation of scientific literature, journals, Web of Science, Science Direct, Google Scholar and archive of scientific Organizations. The next step was a thorough comparison of available water harvesting methods to determine what are the most efficient, practical, economically advantageous and suitable for each researched area.

4. Literature Review

4.1. Water Scarcity

Water scarcity is a widespread challenge that reaches many parts of the world. It is characterised by the inability to fully meet the needs of people and ecosystems within a specific area (Liu et al. 2017). Pressure on water resources increases each year, due to population growth, economic development and greater consumption of animal products. Addressing this issue is crucial not only for the most distressed developing countries but for the overall well-being of our planet since water has an impact on numerous areas of development and is related to the majority of the Sustainable Development Goals (SDGs). It is vital for life itself, promotes healthy ecosystems and fuels economic prosperity. Water is one way that climate change manifests itself, only one in ten natural disasters has a different cause than water and the following risks flow through food, energy, urban, and environmental systems ("Water : Development news, research, data | World Bank" n.d.). Water must be at the centre of adaptation efforts if we are to meet development and climate goals. Considering the growing shortages, maintaining a steady and adequate supply of water is crucial in the effort to reduce global poverty. There are two types of water scarcity affecting different parts of the world, physical and economic (see Fig. 1). When there is not enough water to satisfy the needs of a population or area, it is referred to as physical water scarcity. It is usually caused by the absence of naturally occurring water supplies, such as lakes, rivers and groundwater, or by limitations in accessing water due to geographical or climatic factors (Gude 2017). On the other hand, economic water scarcity is when water resources are accessible but cannot be used to their full potential because of limitations like bad management techniques, poor infrastructure, or lack of funding (Mancosu et al. 2015).

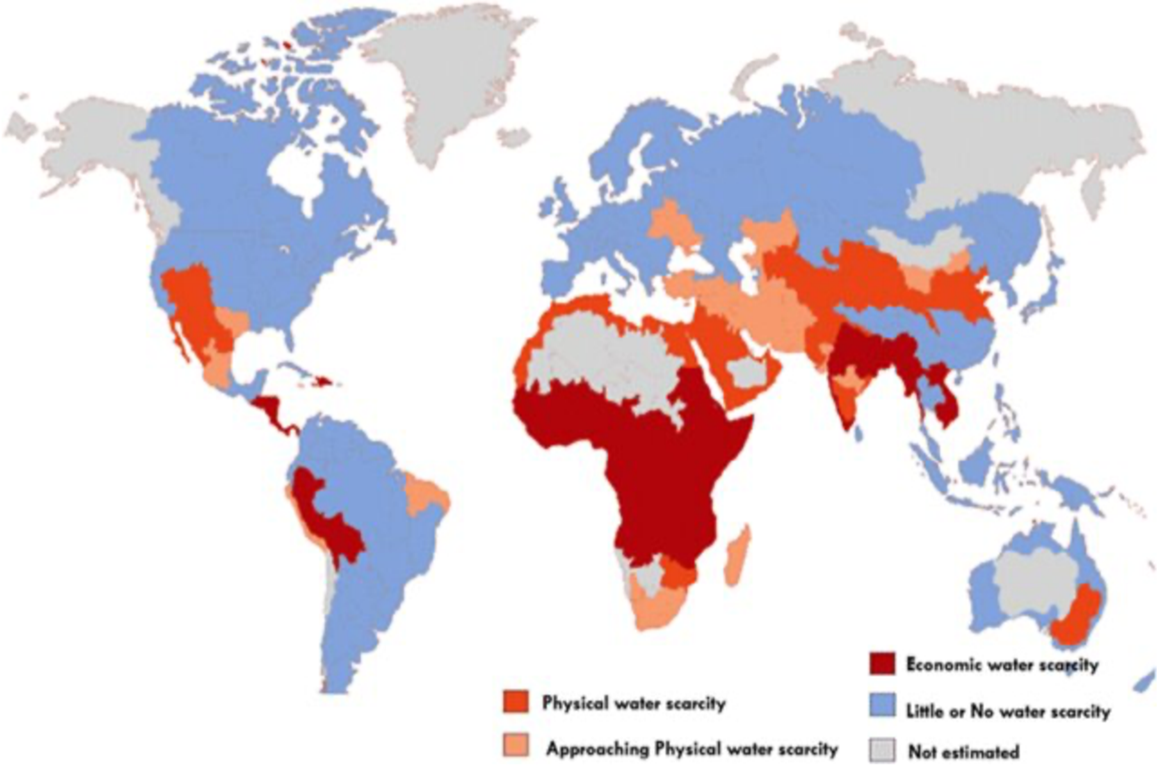

Figure 1: Different types of water scarcity around the world (Gude 2017)

The deficiency of water in those troubled regions significantly impacts agriculture, which is often considered the backbone of their economies and means of subsistence. Insufficient water for irrigation leads to reduced crop yields, food shortages and higher food costs which ultimately affects global food markets (Mancosu et al. 2015). There is an increasing understanding of the fact, that subsistence farmers are unable to benefit from conventional irrigation techniques and water harvesting technologies might have the potential to improve their livelihoods (Mwenge Kahinda & Taigbenu 2011). The gap between water demand and availability has already reached critical levels in many parts of the world and with the expected increase in population and food production, a sustainable approach to water management has never been more important (Mancosu et al. 2015). Water resources can be divided into two groups: non-renewable and renewable. While deep aquifers, which do not refill at a rate that is appreciable throughout the human lifespan, are classified as non-renewable water resources, surface water, including groundwater, and average river flow are considered renewable waterThere are many different indicators of water scarcity, which are essential for decision-making, creating policies and inspiring action to solve one of the most important issues humankind has to currently face. Stakeholders can better work together to attain water security and sustainability for the current and future generations by actively monitoring such indicators, especially in countries with good water conditions, compared to regions in dire need of assistance (Liu et al. 2017). Strategies for water scarcity alleviation can include ("Water : Development news, research, data | World Bank" n.d.):

- Optimising water use through improved planning and incentives.
- Implementation of new water harvest technologies
- Enforcement of economic tools like water licences and prices.
- Investing in desalination, where applicable, as well as in water storage, recycling and reuse.
- Policies that support better water allocation and efficiency must go hand in hand with these measures.
- Increasing resilience and reducing negative economic effects of undesirable events by the improvement of urban design, better crop insurance to take care of farmers, and community involvement ("Waterproofing ")

4.2. Rainwater Harvesting

Most of today's population has some degree of knowledge about rainwater harvesting, its impact, benefits and limitations. It is a sustainable practice for water collection, storage and prevention of runoff (de Sá Silva et al. 2022). Gathered water can be later on utilised for various purposes, for domestic use, agricultural production, habitat restoration, industrial needs and many more.

From using tree leaves as a way to collect rainwater all the way to modern high-tech systems, as long as there was life on Earth, there was some form of rainwater harvesting. Throughout our history, humans and even animals moved to more suitable environments in response to droughts and climatic changes. However, the current political, economic and demographic situation may make it difficult for vulnerable people to relocate or transition to different locations (Ferrand & Cecunjanin 2014). Even though commonly believed that some sort of body of water is needed for life to thrive, it doesn't have to be always true. Past civilisations in Central America, Southeast Asia, Middle East were able to live and sustain themselves in dry, arid environments by focusing on rainwater harvesting (Ferrand & Cecunjanin 2014). Inhabitants of these areas experienced large-scale climate change events during the Late Holocene and those events were significantly more severe than those documented in our history (Ferrand & Cecunjanin 2014). The vast majority of ancient civilizations were agrarian, dependent on favourable climate conditions, no extreme weather and sufficient precipitation (Ferrand & Cecunjanin 2014).

Most of the traditional and ancient RWH technologies were created in reaction to historical climate change events, such as yearly and multi-decadal fluctuations in precipitation, as well as the overall climate of these locations. Many developing countries sharing the same climatic zones today, have dense populations and rely heavily on local, traditional agriculture, with the climate playing a major role in these developments (Ferrand & Cecunjanin 2014). The economically disadvantaged areas of developing rural and climate-vulnerable regions may benefit greatly from RWH technologies if reintroduced and enhanced in some ways. It would lead to increased water and food security which are amongst the biggest issues affecting the local populations. It has a great deal of promise in dry regions alone, but because of a lack of knowledge, high installation costs and overall unfamiliarity, it is not commonly implemented (Bruins et al. 1986). Besides the natural aridity of these regions, there are other factors contributing to insufficient water reserves, such as poor distribution, misuse of resources and ineffective surface irrigation methods (Mahmoud et al. 2016).

RWH can be divided into categories based on the type of catchment surface that each system uses: (1) in situ RWH, which uses a portion of the target as the catchment area (Fig. 2); (2) ex-situ RWH, which uses an uncultivated zone as the catchment area (Fig. 3); and (3) domestic RWH, which gathers water from rooftops, or other clean waterproof surfaces and stores it in large tanks, either underground (Fig. 4) or aboveground (Fig. 5), for private consumption (Mwenge Kahinda & Taigbenu 2011).

Figure 2 in-situ RWH (Mwenge Kahinda & Taigbenu 2011)

Figure 3 ex-situ RWH (Mwenge Kahinda & Taigbenu 2011)

Figure 4 domestic RWH aboveground (Mwenge Kahinda & Taigbenu 2011)

Figure 5 domestic RWH underground (Mwenge Kahinda & Taigbenu 2011)

4.2.1. Implementation of RWH Technologies

Successful implementation of some form of water harvest technologies can mean the difference between life and death, especially in arid and semi-arid regions. Because these areas are often filled with problems, stemming from economic instability, climate change and lack of infrastructure, rainwater collection could bring many benefits with minimal downsides, not only for the developing urban areas but also for rural parts of the country (Umukiza et al. 2023). The collection of rainwater has thousands of years of traditions, nevertheless, with the increasing water scarcity, some changes may have to be made. To ensure the adoption of new technologies, awareness and education about the potential benefits must be promoted (Umukiza et al. 2023). An in-depth study is also necessary to decide whether the rainwater collection systems and practices currently in use can adapt to changing climate conditions and whether they will need to be redesigned to do so (Umukiza et al. 2023).

All RWH systems are made up of the following components (Figure 6) (Umukiza et al. 2023):

- A catchment: This area, commonly referred to as a runoff area, is where rainfall is gathered. The catchment area may be on a rooftop, paved road, rugged terrain, or agricultural land, and its dimensions may vary from a few square meters to many square kilometres.

- A storage facility: This part is in charge of holding the collected runoff water until it is needed for home, farm, or livestock uses. The water can be kept aboveground in reservoirs and ponds, in underground cisterns, or the soil profile.
- A target: This is where the collected rainwater ends up. Here, the water is put to use for farming or household needs.

The method of storing water is primarily determined by the intended usage of the water (Boers & Ben-Asher 1982). In case of need for livestock, some sort of surface reservoir is used. There have been some cases of the same storage type used for crop production, although, soil water storage is considered a better option (Boers & Ben-Asher 1982). The quality and reliability of the storage method depend on appropriate maintenance and management. To stop contamination, algae growth, and waterborne illnesses, storage containers must be actively monitored, cleaned and disinfected. Frequently used RWH techniques in arid and semi-arid countries include ponds, terracing and check dams. In underdeveloped nations, ponds are viewed as one of the most affordable and dependable sources of water (Umukiza et al. 2023). Three techniques are used in agriculture to gather rainwater (Umukiza et al. 2023):

- Micro-catchment: Captures rainwater at a small scale, usually around individual plants or small parts of land. It is used to enhance the moisture of the soil and promote plant growth
- Macro-catchment: Captures rainwater at a larger scale across entire catchment areas by using dams and reservoirs. It is used for irrigation, drinking water supply and in regions with seasonal rainfall patterns even as flood control.
- Floodwater harvesting: Used to redirect excess rainwater during heavy rainfall or flood to prevent flooding and use the water for different purposes, such as irrigation and groundwater recharge.

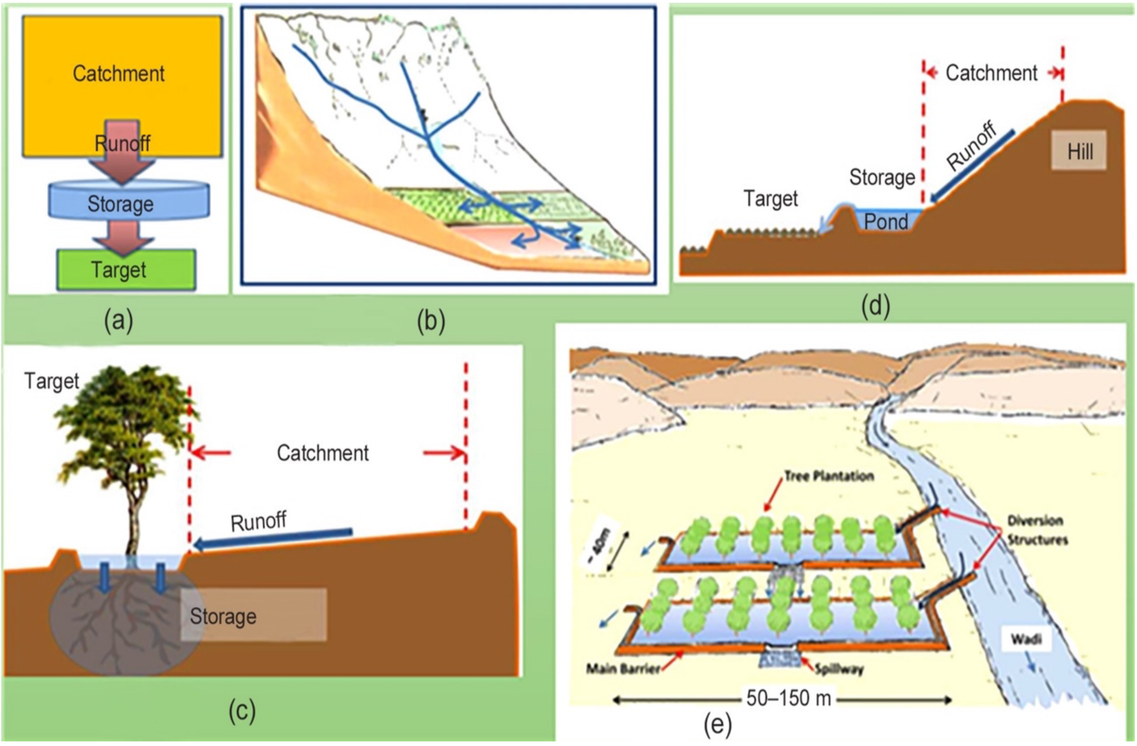

Figure 6. (a) The operation steps of rainwater harvesting; (b) Schematic diagram of macro catchment system; (c) Micro catchment system; (d) Schematic diagram of a macro catchment system with a pond for intermediate storage of runoff; (e) Floodwater diversion (Umukiza et al. 2023)

4.2.2. Benefits and challenges of RWH systems in arid and semi-arid regions

Rainwater harvesting technologies provide a variety of benefits in areas all around the world, but the most beneficial are for arid and semi-arid parts of the planet, where water scarcity poses significant challenges and every drop is a blessing. This method of water collection offers a sustainable solution to elevate water supply and enhance resilience to droughts (Umukiza et al. 2023). Increasing water supply leads to a variety of benefits often crucial for the development and survival of local communities. Poor infrastructure might increase the risks of flooding, although by capturing rain, the volume of rainwater runoff decreases, which helps mitigate the risks in flood-prone areas (Tamagnone et al. 2020). In areas experiencing depletion of groundwater, allowing the rain to get absorbed into the soil rather than being lost to runoff, can replenish underground storage (Jebamalar et al. 2012). Also, rainwater is typically cleaner than surface water sources like rivers or lakes, since it doesn't come into contact with pollutants usually found in urban and rural environments. Because of this, RWH systems increase the quality of water fit for non-potable applications like toilet flushing and landscape irrigation by filtering away debris and different forms of contamination (Rahman et al. 2014).

There are many other benefits to RWH systems: water conservation; decreased need for imported water; reduced risk of erosion; water supply in case of emergencies; potable water price reduction; lower water bill; and employment opportunities (Ngigi 2003). But the biggest of all, is the affordability. In comparison with other water harvesting methods, collecting rainwater is the cheapest by a long shot. Necessary equipment, such as storage tanks, gutters, and filtration systems, is very flexible in terms of scale and cost. Despite requiring large financial investments while working on large-scale infrastructure, in many cases, the locals already own the needed equipment and just after a little preparation, are ready to start small-scale harvesting without any initial investments. In general, rainwater collecting is a cost-effective solution for people, households, and communities trying to improve their water resilience and lessen their dependence on pricey water sources (Oguge & Oremo 2017).

However, there is a few challenges and factors that need to be taken into consideration before deciding if these technologies are worth using for a concrete location. Previous experiences have shown that transferring a specific practice from one area of success to a different one should be done with caution, due to the inconsistent efficiency of RWH methods in response to various environmental and socioeconomic situations (Roba et al. 2022). The focus of recent RWH interventions has been on introducing new systems without significant farmer engagement, but extensive efforts resulted only in minor benefits and poor rates of adoption throughout local communities (Roba et al. 2022). Implementation of RWH technologies demands a comprehensive approach that involves funding, educational initiatives, and measures to guarantee the system's affordability and widespread adoption. It is also critical to keep in mind how important it is for the technologies to be approved and embraced by the local community (Umukiza et al. 2023). Efficiency in arid and semi-arid areas might not be very high, due to lack of precipitation, low humidity and high temperatures evaporating stored water, nevertheless, the importance here is at its highest (Lasage & Verburg 2015). One of the biggest issues for adoption of RWH technologies is the high cost. It requires a significant investment in infrastructure (piping network, storage tanks, filtration systems), due to sparse vegetation cover and limited watertight surfaces making it difficult to find suitable areas for water catchment (Roba et al. 2022). In poor, developing, economically unstable countries, investment of this kind is often a deal breaker.

4.3. Fog collection systems

Fog, a natural phenomenon created by water vapour condensation in the atmosphere, is considered a great alternative source of fresh water, but there might be individuals stating the opposite. There are plenty of negative effects of fog, for example, the pollution of air creates acid fog, which poses a serious risk to human health, corrodes buildings and other infrastructure, and reduces agricultural productivity; dense fog complicates aeroplane landing and take-off, is dangerous for highway driving, and navigation (Shengjie et al. 2010). However, humanity does profit from fog in certain situations. For instance, fog promotes the growth of plants and most importantly presents a valuable possibility to manage freshwater resources and fight water scarcity by using fog collection devices. Similarly to RWH, this paper examines the scientific principles behind fog creation, its history, the technology involved, its uses, and its potential as a globally distributed sustainable water source (Fessehaye et al. 2014).

Several techniques for gathering fog and dew water have been previously recorded, mainly used in arid and semi-arid regions. The most used method was a very simple but sufficient one, water dripping beneath trees was collected and used directly. Many places have historically relied on the naturally occurring fog water that tree leaves collect from heavy fog as a source of drinkable water (Fessehaye et al. 2014). For instance, “fountain” trees, such as pine, juniper, and laurel trees, were the only supply of clean drinking water used for humans as well as animals for centuries in the communities of indigenous people of the Canary Islands. Also, those who lived in the Oman mountains constructed cisterns beneath trees to store fog water for household usage (Schemenauer & Cereceda 1994). Artificial buildings supported fog-water harvesting efforts in other regions. In South America and the Mediterranean region’s deserts, ruins of man-made buildings meant to gather dew and fog have been discovered. Also in Palestine, small, circular, walls were built around vines allowing fog and dew to fall on the vegetation (Fessehaye et al. 2014). Beginning in the early 1900s, scientists became interested in measuring and researching fog as a natural resource in South Africa. Using two rain gauges, scientists attempted to calculate the amount of fog water that plants were able to intercept during this time. The two rain gauges had distinguished settings: reeds were suspended above the second rain gauge, and the first was left in the open like a regular fain gauge. Before Schemenauer and Cereceda (1994) introduced the Standard Fog Collector (SFC) (Fig. 7), this method was widely used to measure fog precipitation (Fessehaye et al. 2014). Today, fog collection systems are used worldwide as an alternative source of fresh water. Countries with successful implementation include Chile, Peru, South Africa, Morocco, Guatemala, Ecuador and many more (Qadir et al. 2021).

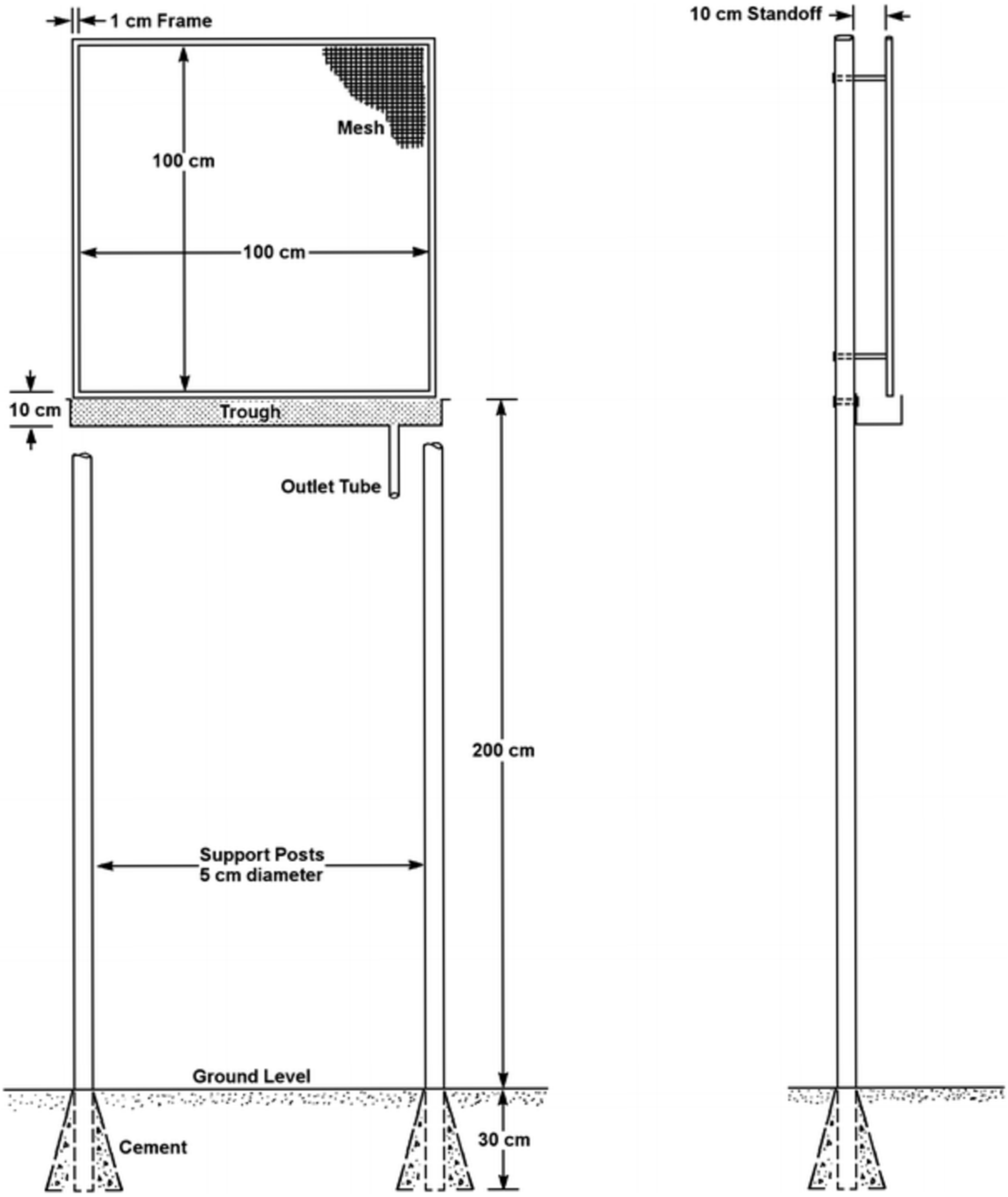

Figure 7 Individual parts of the standard fog collector (SFC) (Domen et al. 2014)

4.3.1. Implementation of fog collection systems

Fog collection technology is an advanced approach that collects fog droplets carried by wind intercepted by the mesh net. Large fog collection systems are set up facing the prevailing wind direction in elevated locations. A portion of fog droplets are caught when near-saturated air flows through a plastic mesh during a fog period (Fessehaye et al. 2014). Small fog droplets combine to generate larger water droplets, which then flow into a PVC gutter attached to the mesh fabric. After the water has been gathered, gravity transports it into a sedimentation tank to remove any suspended materials before reaching an irrigation system or domestic water supply (Fig. 8) (Fessehaye et al. 2014). The greater size of the fog droplets, higher wind speeds and narrower collection fibres all contribute to increased collection process efficiency. Furthermore, a porous medium with adequate drainage properties is needed (Batisha 2015).

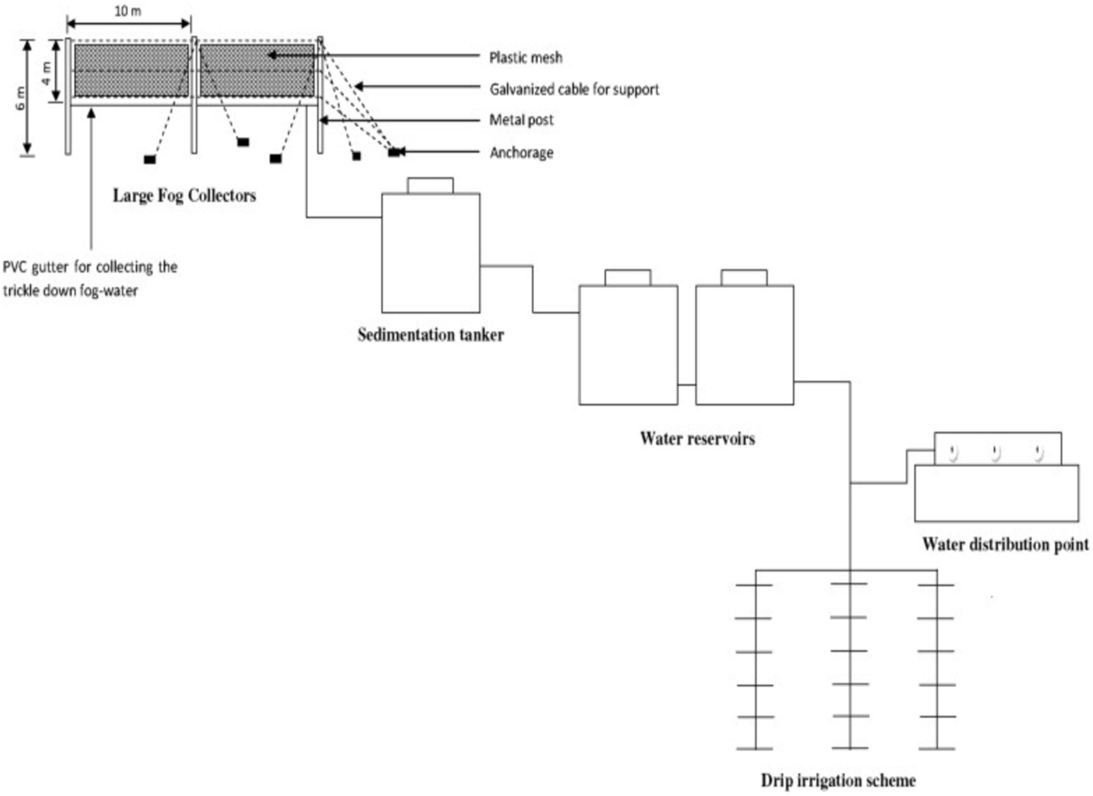

Figure 8. Fog collection system (Fessehaye et al. 2014)

To guarantee effective installation and functioning of fog collection systems, several precautions must be carefully followed. Choice of the right place is the most important first step. It requires careful consideration of the geography, the weather and fog patterns to select the optimal site. Locations in hilly or coastal areas with high fog density and frequency are usually chosen (Figure 9) (Qadir et al. 2021). Secondly, the evaluation of different factors such as final costs, needs of the community, regulatory issues and water yield potential can greatly contribute to a successful implementation (Domen et al. 2014). Also, maintenance and monitoring are essential to ensure proper functioning and stable quality. Water yield, water quality metrics, and system performance should all be tracked via established monitoring techniques. It is recommended to establish routine maintenance including cleaning of collection surfaces, inspecting support structures, and swiftly addressing any faults or damage (Qadir et al. 2018). It is also believed that to maximize the benefits of fog harvesting, one should use the technologies alongside other water supply methods, not in place of them. A sustainable operation of fog harvesting projects provides enough fresh water to many locations across many nations. Key success factors include education, training, public involvement from the local community, awareness-raising, and capacity building (Batisha 2015).

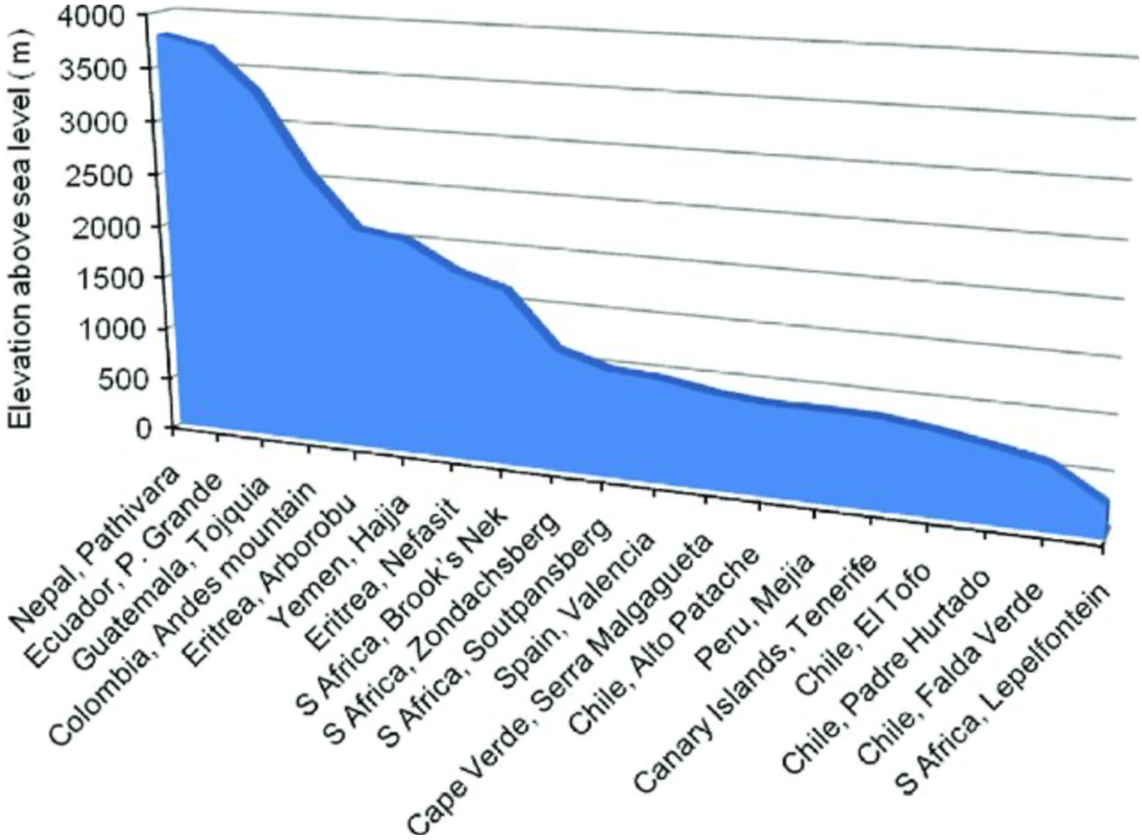

Figure 9 Locations and elevation of fog collection technologies (Fessehaye et al. 2014)

4.3.2. Benefits and challenges of fog collection systems in arid and semi-arid areas

In arid and semi-arid areas where conventional water supplies are limited, fog collection technologies are gaining popularity as a viable solution to the problem of water scarcity. While there are many advantages to fog collection, like increased water security and environmental sustainability, there are drawbacks as well, including site suitability issues, technological limitations, and worries about water quality. Economically speaking, fog collection systems are full of positives. A lot of resources are required during the installation process, but afterwards, very little funding and minimal maintenance are needed to ensure uninterrupted operation (Batisha 2015). Besides this, fog collectors also support sustainable agriculture, small-scale enterprises, and eco-tourism, contributing to poverty reduction and economic development. Also, not suffering from water scarcity and having daily access to clean drinking water greatly impact people's livelihoods, improve overall health, and empower the community (Klemm et al. 2012).

Despite having so many benefits, there are still a few disadvantages that should be taken into consideration. The main challenge of implementation is the need for a specific location and seasonability. Favourable topoclimates and altitudinal gradients are necessary for fog creation, ideally around coastlines. Since not every part of the world has this ideal natural environment needed for the efficient use of fog nets, the technology's application to specific coastal regions and mountain ranges (Fessehaye et al. 2014). The occurrence of fog is seasonal, and its duration varies globally. Some places, like the north coast of western Chille, experience fog all year round, while other places, like Oman, have limited periods of fog (60 days) despite having a high rate of collection. As a result, the supply of fog water typically becomes seasonal, forcing local communities to either install more water delivery systems or pay more for additional storage to have more fog water available for fog-less periods (Fessehaye et al. 2014). Even though no daily maintenance is needed, fog collection systems should undergo regular maintenance and monitoring from qualified community members. This involves repairing ripped mesh, tightening loose cables, and in the worst-case scenario, rebuilding collapsed meshes. The technology may encounter difficulties and eventually be discontinued, as has been the case in many nations if communities are not fully committed to preserving the system's functionality (Batisha 2015).

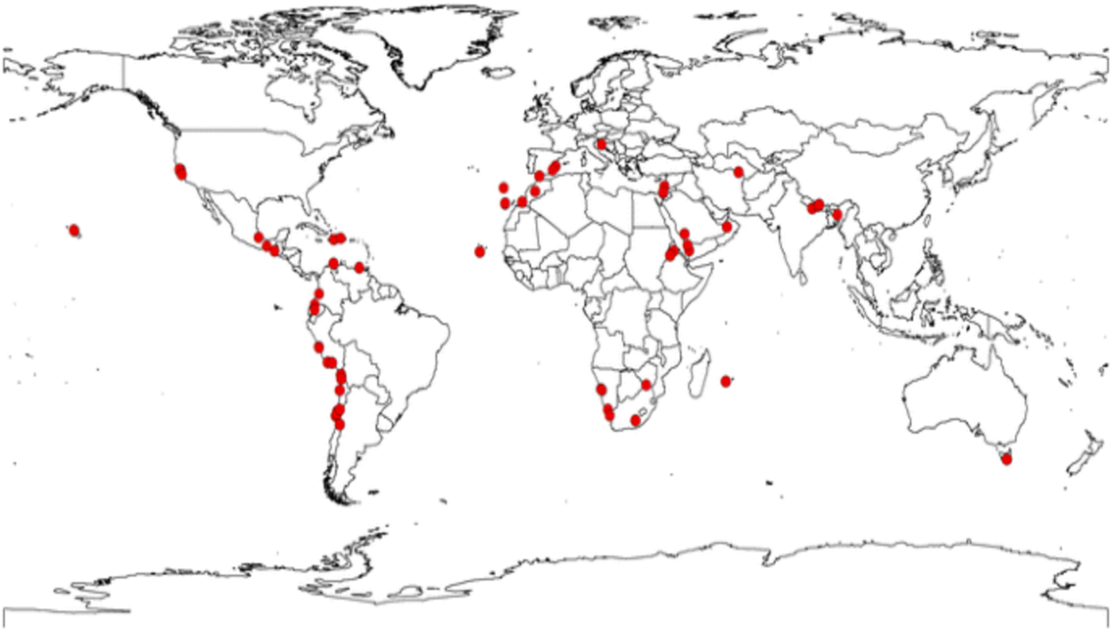

Figure 10 Potential areas of fog collection success (Domen et al. 2014)

4.4. Desalination facilities

Desalination, the process of purifying seawater or brackish water by removing salts and other contaminants to create freshwater, has become an essential tool for managing water resources, especially in arid or semi-arid areas, along the coast, or on islands where freshwater supplies are scarce (Elsaid et al. 2020). It is an attractive potential solution to the long-standing problem of seawater abundance and practical inaccessibility for potable usage, as it indicates the prospect of an almost limitless supply of clean water. Even though this method of water harvesting gained popularity not so long ago, the fundamental concept of this technology is not unheard of. This technique has been applied in one form or another throughout human history on a global scale (Asli et al. 2023). Desalination technology had to keep changing to meet the different needs of the current population. This has caused this technology to undergo an evolutionary process to adapt to these new, complex, and demanding water requirements. In the past, attempts to desalinate water had two main goals: first, to recover and extract the minerals for their financial worth, and second, to secure more water of high-quality (Asli et al. 2023). For the purposes of this paper, my main focus is on the latter.

Despite the long history of desalination, going back thousands of years to when primitive societies used basic distillation methods to turn saltwater into seawater, the development of innovative methods and technology in the 20th century to satisfy the rising need for freshwater is considered the beginning of the modern era of desalination (Angelakis et al. 2021). While it is frequently challenging to pinpoint certain historical desalination milestones due to contradicting material, many academics agree that the world’s first traditional thermal desalination plant was constructed in Sliema, Malta around the year 1881. Around the same period, similar businesses were found throughout Latin America, especially on the Pacific coast of Bolivia, Chile, and Peru (Asli et al. 2023). Following was Saudi Arabia, building many plants around the 1950s in Kuwait, Bahrain and Qatar. Large sand filters were used as a pretreatment step for the water (Angelakis et al. 2021). Shortly after followed European nations experiencing insufficient water, Spain was first and chose the Canary Islands as the location to battle water scarcity. During this period up until the 1980s, the US established its position as a pioneer in this technology and committed to developing and improving the desalination process as a whole (Asli et al. 2023).

Over time, the desalination process has become more and more common. Around the world, there are currently over 20,000 desalination plants operating with a combined capacity of over 100 million m3/d. Over 330 million people suffering from water scarcity do not get their water from desalination facilities. Furthermore, the Middle East and North Africa are listed as having 53% of the world's desalination capacity. The largest ones are in the United Arab Emirates, Israel, Australia, and Saudi Arabia. With limited water resources and low energy prices due to the use of fossil fuels, Saudi Arabia (Ras Al Khair) is home to one of the largest desalination plant in the world. It can hold 1 401 000 m3/d of water (Angelakis et al. 2021).

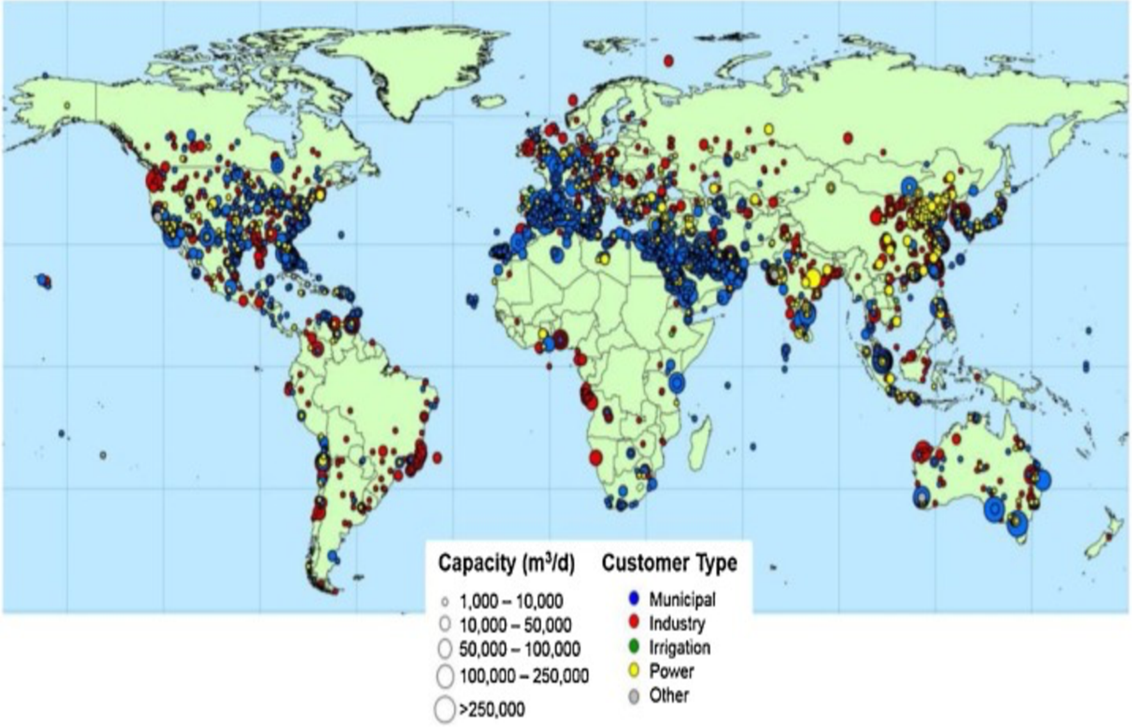

Figure 11 The world share of desalination plants (Soliman et al. 2021)

The global expansion of this business is depicted in Figure 12. It is evident that the desalination sector is expanding gradually in terms of overall capacity as well as the number of installed desalination plants. Also, growth has accelerated throughout the last 20 years. Nevertheless, due to regional differences in socioeconomic situations and local water demand, desalination project development differs greatly from location to location (Asli et al. 2023).

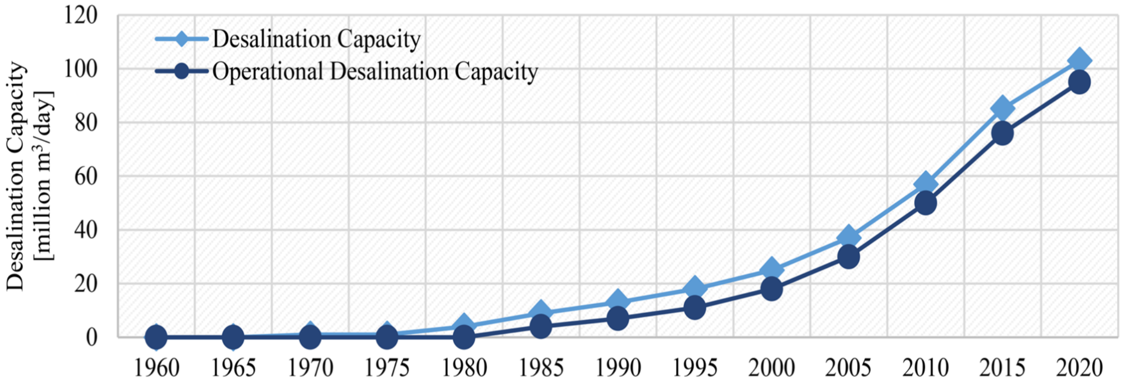

Figure 12 The evolution of desalination capacity over the years (Angelakis et al. 2021)

It should be mentioned that various methods approach the desalination process in different ways. Even though these technologies have similar end goals, there are significant distinctions between them, including compatibility with various energy resources, average energy consumption, and the quality of the water used for intake and output. Thermal desalination and membrane desalination are the two methods used by desalination plants to provide freshwater suitable for industrial use. Sometimes, a combination of these methods can be used (Younus & Tulou 2005). Thermal-based desalination uses the water's liquid-vapor phase characteristics to extract water from salt. By using thermal energy to evaporate water, which is then condensed and collected at a different place. The energy might come from gas turbine cycle waste heat or solar thermal collectors, or it can come directly from electric heating (Kwan et al. 2022).

The membrane separation-based desalination technologies consist of electrodialysis and reverse osmosis (RO) techniques. Reverse osmosis is already a well-established product that has been used for decades (Kwan et al. 2022). Fig. 13 depicts its fundamental structure, which consists of a membrane that allows water to pass through but stops salt molecules. When the solution is pressurised over its osmotic pressure, which varies depending on the salinity concentration, water can pass through the membrane and be collected as the desired product (Kwan et al. 2022). Usually, the RO-based approach uses less energy than thermal desalination systems. Additionally, a combination of RO with solar power is an effective method of reducing the carbon footprint that comes from burning fossil fuels. Nevertheless, the chosen membrane material is frequently not ideal and could allow small quantities of salt ions to leak into the permeate freshwater. Because of this, RO-based desalination is less suitable when aiming to have very pure water or when the concentration of saltwater is more than typical ocean values, approximately

3.5%. Several Middle Eastern countries prefer the thermal desalination method, due to the poor quality of seawater from the Red Sea. Nowadays, RO has become the most widely used desalination technique, accounting for roughly 60% of installed capacity worldwide. An extra 35% is accounted for by thermal desalination (Tal 2018).

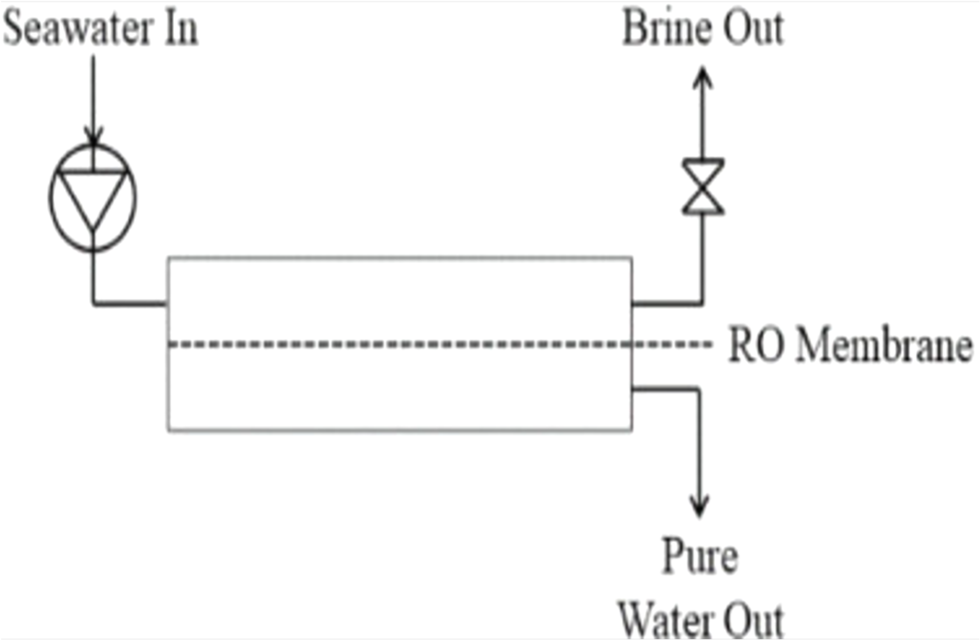

Figure 13 Schematic of the RO desalination method (Kwan et al. 2022)

The second method of desalination, thermal-based desalination, uses the water’s liquid-vapor phase characteristics to extract water from salt. Water vapour is subsequently condensed at a different place for collecting after thermal energy is applied to cause evaporation. The thermal energy can be produced by solar thermal collectors, or from electric heaters, or by waste heat of the gas turbine cycles. This type of desalination is further divided into Multi-effect distillation (MED) and Multi-stage flash (MSF) (Figure 14) (Kwan et al. 2022). Since a vacuum environment lowers the boiling point of water and speeds up its evaporation, it is frequently present in the enclosed chambers in both situations. Each stage of the plant should have a vacuum pump installed, which operates to remove any non-condensable gases from the atmosphere (Kwan et al. 2022). In Figure 14 (a) is a usual MED structure of 3 stages. Superheated steam is produced in the final step of the MED plant and is used to transmit heat into seawater to separate the water at each stage. Steam condenses into the freshwater product for collection as it transfers heat with the seawater. Typical structure of the MSF is shown in Figure 14 (b), and same as MED, can also have various number of stages. By repeatedly exchanging heat with the superheated steam at each level of the plant, the seawater is preheated in this system. It is then passed directly in the opposite direction to the entering seawater after being heated in a boiler to the temperature necesarry for a fast evaporation. MSF has been more successful than MED because of its more dependable performance and easier to use layout. Research indicates that raising number of stages, the specific heat transfer area, and the top brine temperature can all improve MSF performance. Moreover, the pairing of solar thermal energy to MSF plants is a frequent technique, much as the MED plants (Kwan et al. 2022).

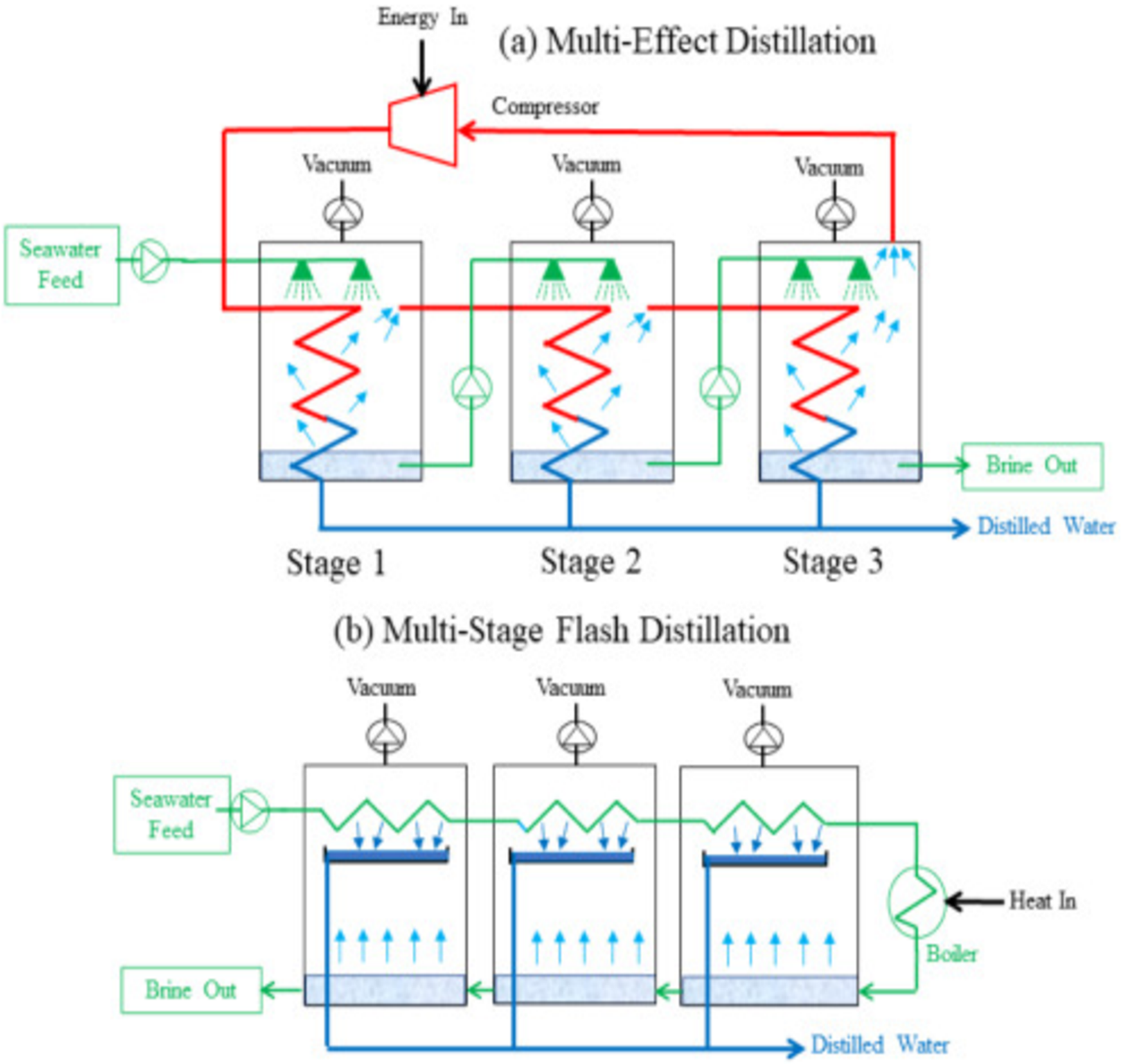

Figure 14 Schematics of the common thermal-based desalination technologies (Kwan et al. 2022)

In the case of small-scale, low-cost production, desalination technology that takes advantage of free solar energy is essential. The less expensive version of this technology is solar stills, particularly in regions with lots of sunshine. However, several issues prevent solar stills from being widely used, one of which is that when solar radiation decreases after nightfall, solar still performance sharply declines. Some alternatives are suggested to overcome this constraint, such as installing photovoltaic panels (PV) to increase solar energy output or thermal energy storage (TES) devices to extend the still's operating hours past dusk (Jafaripour et al. 2023).

4.4.1. Implementation of desalination facilities

As was already mentioned, desalination facilities give us another way of collecting fresh water. To ensure optimal functioning and avoid unnecessary problems, there are several steps and factors affecting successful implementation that should be taken into consideration. Before even choosing the correct site, an evaluation of factors, including technical feasibility, economic viability, and environmental implications, must be done. One of the most important parts of the whole process, site selection, is the following step. While deciding on the perfect location, things like accessibility to a supply of water and energy sources, availability of infrastructure and land, and environmental considerations should be taken into account (Younos 2005). As with any other new technology, engaging with local populations before starting a project is crucial for a variety of reasons. First and foremost, it enables project developers to better understand the particular requirements, worries, and goals of the community. Developers can minimise potential disputes and match the project design and execution process with local preferences by talking and listening to the community members (Liu et al. 2022). Including locals in the decision-making process also promotes accountability, trust, and transparency. It shows respect for the local wisdom, customs, and values, which strengthens multi-cultural relations and encourages local people's adoption of the project. Interacting with the communities also helps to clear up any misunderstandings or fears about water management techniques, environmental effects, and desalination technology (Liu et al. 2022). After following said steps and making sure, that the implementation doesn't break any laws or policies, it is time to turn an idea into reality.

4.4.2. Benefits and challenges of desalination facilities in arid and semi-arid areas

Desalination technologies are remarkable inventions of modern engineering offering a glimpse of hope into the progressively increasing water-scarce world, by transforming the vast available quantities of seawater into freshwater suitable for industrial and human use. It is a step towards sustainable water management, but it’s not without its risks and challenges. Probably the biggest advantage is that collecting water using desalination, eliminates our dependency on traditional water supplies and unpredictable precipitation, especially in arid and semi-arid regions (Gibson et al. 2015). Desalination also lessens reliance on limited freshwater resources like rivers and aquifers by tapping into abundant brackish groundwater or seawater. This diversity reduces the risks associated with water scarcity, increases overall water security and provides a safety net during droughts. Just the construction and operation of these technologies provide jobs and support local economic growth, positively affecting the entire country (Gibson et al. 2015). Furthermore, water from desalination plants is a dependable source of drinking water, since it has no trace of pollutants and microorganisms. Desalination can enhance public health outcomes by lowering the prevalence of waterborne illnesses and raising sanitation standards in areas with limited access to clean water (Fielding et al. 2015). Moreover, the implementation of desalination technology gives a chance for worldwide innovation and cooperation. International relations and partnershios can be fostered by exchanging knowledge and skills in desalination research and implementation, particularly when countries face the urgent challenge of water scarcity. This cooperative strategy promotes group efforts towards sustainable water management practices while also advancing technology breakthroughs.

Despite its benefits, some drawbacks should be kept in mind. One of the main drawbacks of this technology is its high energy consumption. Reverse osmosis, the most popular membrane treatment method for desalination of brackish water, requires around ten times as much energy per unit of water as conventional surface water treatment (Clayton et al. 2014). Combining it with renewable energy sources, such as wind, makes it possible to produce fresh water without becoming more dependent on fuels emitting carbon dioxide. Desalination facilities can also be turned on and off or run at off-peak hours when there is less demand on the grid and wind is available. On the other hand, the construction of a brackish groundwater desalination plant using wind-generated power faces obstacles because it needs the geographic accessibility and economic feasibility of the two resources close to each other (Clayton et al. 2014). Due to the high operational costs, it is very challenging for small communities or regions with limited financial resources to afford such technologies (Mezher et al. 2011). Moreover, the construction of a desalination plant needs a large initial investment in infrastructure and technology, making it almost impossible to implement without help from outside investments or the government (Eke et al. 2020).

Lastly, the environmental impact evaluates how desalination can harm the natural world in various ways, which includes (a) the unregulated discharge of concentrated brine, which has the potential to contaminate aquifers and harm marine ecosystems. Pretreatment chemicals, corrosion materials, or even radioactive contaminants (if the desalination facility is connected to power plants), may all be present in the brine discharge. Total dissolved salts, temperature, and density of the discharge are highly significant factors that affect the aquatic environment's health when it comes to the harmfulness of released brine concentrate (Mezher et al. 2011). (b) A connected power plant provides the thermal and electrical energy needed for operation. This process's energy utilisation results in a certain amount of carbon dioxide emissions contaminating the environment. Generally speaking, indirect environmental impact decreases, if the energy requirements during desalination also decrease. Last but not least, (c) chemical spills, gaseous emissions, and noise pollution from desalination plants. Facilities in highly populated areas may affect the neighbourhood. Certain desalination systems release harmful fumes and produce noise due to the operation of high-pressure pumps. If the property is close to populated areas or public spaces, the design should incorporate measures to reduce noise levels, such as using canopies or acoustical planning (Younos 2005).

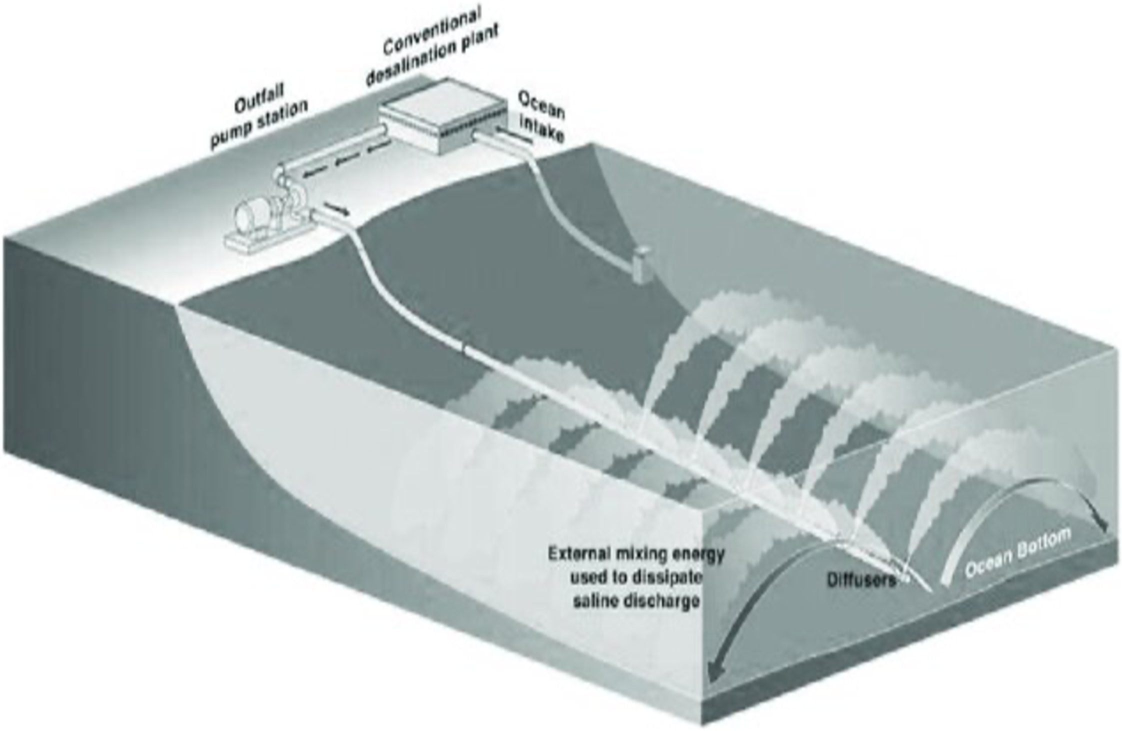

Figure 15 Schema of a brine discharge system at a desalination plant (Meftah & Mossa 2018)

4.5. Examples of water harvesting projects fighting water scarcity

After spending a good deal of time researching various water harvesting technologies, learning about their history, types, ways of implementation, benefits and challenges, it is clear that real-world examples provide priceless insights and deepen our understanding of the topic and it is the best way to determine most suitable technology for different areas of arid and semi-arid world. We can observe the difficulties, successes, and complexities of water harvesting projects firsthand by immersing ourselves in these real-life circumstances, which provides us with an abundance of practical learning opportunities. Also, by analysing real-world instances, we can spot trends, patterns, and best practices that would not be visible through scholarly research alone.

Essentially, real-world examples promote greater research, critical reflection, and contextual understanding, and fill us with inspiration, whereas theoretical frameworks offer a strong foundation for a better understanding of water-related topics. By embracing both theoretical concepts and examples of practical application, we may develop a deeper understanding of water harvesting technologies and their role in alleviating water scarcity. Many effective water harvesting projects have been successfully implemented in arid and semi-arid regions, demonstrating creative solutions to the problem of water scarcity.

4.5.1. FogQuest – Tojquia, Guatemala 2006-2016

FogQuest is a small Canada-based non-profit organisation dedicated to planning and carrying out water projects for rural people in underdeveloped nations. It employs only volunteers and was founded in 2000 by Dr. Robert Schemenauer and Sherry Bennett ("FogQuest: Sustainable Water Solutions | Fog Collection | Rainwater Collection | Rural Water Projects" n.d.). Their specialisation is the utilisation of innovative fog collectors, also effectively used as rainfall collectors, to maximize the usage of atmospheric water sources found in nature ("FogQuest: Sustainable Water Solutions | Fog Collection | Rainwater Collection | Rural Water Projects" n.d.). FogQuest grows thanks to the knowledge acquired from projects taken since 1987, which have consistently demonstrated the feasibility and efficiency of employing fog collectors to provide clean water to developing nations across the globe. The three main sources of funding for their operations are annual individual membership fees, corporate donations, and grants from organisations for fieldwork. By paying the reasonable membership fee, one gains access to the vast FogQuest library containing their manual and over 400 scanned articles ("FogQuest: Sustainable Water Solutions | Fog Collection | Rainwater Collection | Rural Water Projects" n.d.).

Figure 16 FogQuest logo ("FogQuest: Sustainable Water Solutions | Fog Collection | Rainwater Collection | Rural Water Projects" n.d.)

Tojquia sits in the western highlands of Guatemala's Huehuetenango region at a height of 3300 metres, close to the summit of Chuchumatanes mountain. Due to the high altitude, Tojquia experiences severe water shortages. During the dry season, November to April, fog is the only supply of fresh water needed for daily life. On the other hand, many families were able to collect great quantities of water nearly every day by placing buckets and containers beneath their home's roofs. In many developing countries, it is the women's role to get clean water, so before the implementation of this project, women and their daughters had to walk to old wells far outside the city to bring back water for their families (Schemenauer et al. 2016). Before starting the project, FogQuest monitored the use of Standard Fog Collectors (SFCs) in several regions of Guatemala. Just by installing 1m2 of SFCs, they gained insight into the potential amount of water harvested and also learned about the community's dedication and cooperation in the project. The men and women of Tojquia demonstrated a great work ethic and dedication to the project which was essential to its eventual success (Schemenauer et al. 2016).

FogQuest started working in the Guatemalan Western Highlands in 2005 when four Large Fog Collectors (LFCs) were built in La Ventosa. In 2006, four LFCs were also built in Tojquia and just a year later six more were added. After this, the project expanded quickly to 35 LFCs. This quantity of LFCs can provide 7000 L of fog water every day during the six-month dry season, it is an area of roughly 1400 m2. After supplying the village's houses with clean water for ten years, these 35 LFCs are still functioning and productive (Klemm et al. 2012). The success of this project has been largely dependent on the ongoing cooperation with local residents. The FogQuest method involves having several members instruct, coordinate, and mentor the villagers during the first stages of building, and eventually involving the community as active participants in the project's development. The Tojquia people have even formed a water committee to start building new fog collectors while looking after the already existing ones. Adoption of this water resource does not need further improvements in technology, instead, it requires thoughtful site selection and patient, compassionate guidance that results in strong lasting partnerships with the local population (Schemenauer et al. 2016). Nonetheless, it is possible to identify four factors that are critical for the accomplishment of this particular project: (1) The ability of FogQuest to adjust to the unique needs and characteristics of the local area; (2) The co-creation, technology transfer, and management that went on; (3) The community's dedication and independence throughout the project's interactions; and (4) The hands-on involvement of community groups and village leaders (Schemenauer et al. 2016).

Figure 17 Two Large Fog Collectors in Tojquia (Schemenauer et al. 2016)

4.5.2. Israel – desalination and water management

Israel's water management is characterized by innovative strategies and technologies used to address the country's water scarcity challenges. There are three factors affecting Israel's water management: First, even though the north receives a lot of precipitation, the majority of their agricultural land is located in the south; second, the primary irrigation season is during summer, however, rainfall events usually happen in the winter; and third, there is a lack of freshwater naturally, and with the fast-growing population together with frequent successive droughts, it is only going to get worse, if nothing is done (Slater et al. 2020). In order to address these issues, Israel built an elaborate water distribution system that covers the majority of the nation's regions. They started to use treated wastewater and brackish water for agriculture, while more recently, even large-scale seawater desalination plants were slowly being implemented (Slater et al. 2020).

The Dead Sea is arguably the best representation of the Middle Eastern water shortage. Only specially adapted bacteria and fungi can survive in its salty water (10 times saltier than the ocean) (Kramer 2016). Its vital resource, the Jordan River, was diverted to provide water to Israel, Syria and Jordan, leading to a yearly decrease in the Dead Sea's level (Kramer 2016). While suffering from water scarcity, Israel has emerged as a leader in sustainable water management, to the point that its government announced in 2013 that the country's water supply is unaffected by the arid environment and unpredictable weather (Kramer 2016). Israel is considered one of the leaders in desalination technology and water management innovation. Currently, 30% of Israel's potable water resources come from desalination, from five reverse-osmosis plants, annually producing about 582 million cubic meters of exceptionally high-quality water at a price that rarely goes beyond 60 cents per 1000 L (Tal 2018). From $1.60 per cubic metre in the 1990s, prices have decreased to approximately 58 cents now . They use sand filters to remove larger debris from the water collected from the Mediterranean Sea. After that, the seawater is pushed through multistage cylindrical polymer filters at very high pressure. Large molecules, microbes, and other particles are trapped by progressively narrower pores. As much as 99.8% of the salt and other minerals are retained, letting almost pure water pass through the RO membrane in the last stage. Although the permeate is close to pure, traces of boron still must be removed via a post-RO treatment, since even the smallest amount is harmful to plants (Kramer 2016).

Israel is home to many desalination facilities including one of the biggest desalination plant in the world, Sorek. Opened in 2013, using reverse-osmosis technology it operates at a yearly capacity of 150 million cubic meters (Tal 2018). The cylindrical parts of Sorek have widths of 41 cm, making them twice as wide as those at other Israeli plants. Their vertical arrangement saves floor space and simplifies cleaning and restarting the RO process with ease. Significant financial investment was required for proper implementation, for example, the plant has some 50,000 filter elements, each worth $2,000 (Kramer 2016).

Figure 18 Sorek desalination plant (“Sorek Desalination Plant - Water Technology” n.d.)

Regarding water management innovation, Israel also shows promise in wastewater treatment. Considered one of the largest and most complex facilities, the Shafdan plant treats approximately 400,000 cubic meters of wastewater daily from a population of over 2.5 million people are treated at the Shafdan plant (Kramer 2016). In Israel, treated wastewater is limited to only be used in irrigation. It is provided by the state via a specialised distribution network. Compared to the World Health Organisation, Israel has stricter regulations for treated water used in agriculture (Kramer 2016). Also, modern drip irrigation was developed in Israel and provides water, including earlier treated wastewater, straight to the roots of crops and plants. Drip irrigation works well on steep slopes and accurately applies liquid pesticides and fertilisers where needed. It also leads to reduced water use and evaporation compared to sprinkling (Kramer 2016).

Figure 19 Shafdan wastewater treatment plant ("The Shafdan R&D Center – An open installation for wastewater treatment and effluent reclamation solutions - Global Water Intelligence" 2020)

As mentioned before, the implementation and maintenance of desalination plants have some downsides. The related carbon footprint is at the top of the list of negative environmental effects linked to the widespread use of desalination worldwide. Instead of using the far more energy-intensive thermal distillation method, all desalination plants in Israel use reverse osmosis to have lower energy input. However, significant energy is needed in the RO process in order to pressurise water enough to pass through semipermeable membranes. This shows that the amount of energy needed depends on the salt content of the water supply. Facilities receiving water from brackish groundwater (which has salinity lower than seawater), consume less energy than those that receive it from the ocean (Tal 2018). Israel has relied on a national water carrier to supply the majority of its drinking and farming water from Lake Kinneret, the Sea of Galilee, for the majority of its history. Today, pumping one cubic metre of water from the lake to Israel's people requires between 0.4 and 1.0 kWh. However, this seems small in comparison to the second option, which uses 3.0-3.5 kWh of energy per cubic metre of water generated by a desalination plant. The high cost of desalination plants has always been among the biggest issues. Reducing the amount of energy needed for production results in a decrease in greenhouse gas emissions as well as operational costs (Tal 2018). The employment of more effective pumps, the installation of energy recovery devices, and improved highpermeability membranes have all contributed to this advancement. As a result, the energy costs related to running the five main desalination plants in Israel have already decreased by about 300 per cent (Tal 2018).

As for the impact on marine ecosystems, a study monitoring the effects of brine discharge on seawater quality in the Eastern Mediterranean has concluded that the disposal of brine did not reduce water's quality, besides some irregularities at the outfall, higher temperature and salinity. Nevertheless, this is a brief study covering the first six years of brine discharge. Whether the study's findings show a consistent pattern over time, if they might change over time, or if they are just the beginning of a slow impact (Kress et al. 2020). The waters along Israel's Mediterranean coast are also being monitored regularly by the Israel Oceanic and Limnologic Institute to ensure minimal pollution (Tal 2018).

5. Conclusions

The exploration of water harvest technologies has provided valuable knowledge and insights about individual practices and their potential to alleviate water scarcity. Thanks to the examination of real-world examples such as FogQuest's fog harvesting projects in Tojquia, Guatemala, or Israel's modern approaches to desalination and water management, many lessons and information have been gained.

FogQuest's initiatives highlight the potential of fog collection systems to provide a sustainable freshwater source, particularly where traditional sources are lacking. Similarly, Israel's advancements in desalination technologies demonstrate how technological innovation can turn sea or brackish water into a viable resource, easing the impact of water scarcity on various sectors. These studies highlight the adaptability and effectiveness of water harvesting technologies in addressing the unique challenges of water scarcity.

In the world of water collection methods for arid and semi-arid areas, understanding the strenghts, and weaknesses, as well as the opportunities and threats, is crucial for strategy planning desicion making. A SWOT analysis provides a structured framework for evaluating the internal and external factors that influence the implementation of water harvesting projects.

- **Strenghts:** additional supply of fresh water, adaptability to various conditions, reduced reliance on natural resources can minimize ecosystem degradation,
- **Weaknesses:** dependant on climatic conditions, high initial investment, some machinery requires specialized skills to look after, not very effective at a large scale
- **Opportunities:** continued research can lead to innovation in efficiency and cost reduction, policies and incentives from the government to adopt suitable water harvesting methods and promote sustainability, collaboration and partnerships between organisations

- **Threats:** high prices of implementation, high energy inputs of desalination facilities, conflicts between the locals and investors, governance constraints

After extensive research and evaluation of dozens of articles, some recommendations to harness the full potential of water harvesting technologies can be made:

1. **Invest in research and development:** Advancement in efficiency and effectiveness, as well as means of cost reduction, would make the technology more accessible and in demand.
2. **Promote collaboration and community involvement:** Collaboration with local communities and stakeholders is crucial to ensure success of water harvesting projects. It could mean involving members of the community in the planning process or seeking input from local experts.
3. **Look for support and funding:** Try to get various sources of funding such as government grants, private donations, support from NGOs etc., so that poor communities get help with the initial financial investment.
4. **Spread awareness and education:** Raise public awareness about water scarcity issues and the benefits of water harvesting technologies. Communities need to know about sustainable water management practices, so that they can save water themselves. Schools, community centers, and media outlets should empower individuals to conserve water resources and mitigate the impacts of climate change.

While water scarcity remains a formidable challenge, the advancement and implementation of water harvesting technologies give us hope for a more sustainable and resilient future. By focusing on innovation, collaboration, and strategic investments, we can build a future without the challenges of the present. It is through these combined efforts that we can overcome the obstacles of water scarcity, and guarantee access to clean water for future generations.

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