Is Rainwater Harvesting a Solution for Water Access in Latin America and the Caribbean?

An Economic Analysis for Underserved Households in El Salvador

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Abstract[1]

This paper assesses the potential of rainwater harvesting systems (RHS) as an option to expand water access, increase equity and address increasing pollution of surface and ground water resources in Latin America. The paper focuses on the case of El Salvador because it is one of the most pressed countries in terms of water scarcity and pollution of water resources. Other issues include regulation, inefficiency in operation, inadequate cost recovery and lack of investment, challenges generated by climate change and greater citizen pressure for the guarantee of the right to water. The paper develops a model for rainwater harvesting using country-specific environmental and financial variables including rainfall patterns, consumption and alternative water sources. A cost-benefit analysis is performed across several scenarios, concluding that RHS offer a cleaner and less expensive source of water for households not connected to the water grid, or for those that due to poor service must purchase some water. Communal systems prove to be more efficient than individual installation in some cases. RHS also offer positive impacts on equity and hold the potential to be a solution for water access for underserved households.

JEL classifications: L95, L97, Q25, Q53
Keywords: Rainwater-harvesting systems, El Salvador, Cost-benefit analysis, Rural water access

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1. Introduction

The supply of water for human, agricultural and industrial purposes, guaranteeing the sustainability of the resource is one of the challenges of all societies in this century. The sixth Sustainable Development Goal proposed in the United Nations involves access to clean water and sanitation, and six specific targets were defined as milestones for this goal: equitable access to drinking water, equitable access to sanitation and hygiene, reducing water pollution, increasing water-use efficiency, implementation of integrated water resources and protection of water-related ecosystems.

The goals set by the members of the United Nations aim for a solution of the main challenges of the water sector across the world, including Latin America. The region exhibited a significant improvement in water access and sanitation indicators in the 1990s, but important gaps remain in terms of equitable access for poorer and rural households.

The water sector in the region suffers from inefficient tariff structures and incomplete or incoherent regulatory frameworks that hamper good governance (Bertomeu and Serebrisky, 2018). In addition, an important share of surface and ground water sources are polluted or unprotected in most countries in the region.

Apart from the traditional issues related to access, regulation and pollution, challenges facing the water sector include the effects of climate change, which has heterogeneous effects on the region. In addition, citizens' demands for equity and the guarantee of the right to water are important in democratic countries and represent another source of pressure for governments and other actors in the water market.

El Salvador is one of the countries in the region where most water-related issues converge (UNDP, 2010). The three most pressing are the low rate of access to water—particularly in rural areas—low efficiency and inadequate cost recovery. The main public provider, the National Water and Sewerage Administration (known as ANDA) suffers from the usual problems of state-owned enterprises, including low tariffs, poor quality of service, low efficiency, poor accountability and inadequate capital investment.

A centralized solution to issues plaguing the water sector has been difficult to reach as legal reform has stalled for almost two decades due to conflicting interests and social pressures. Thus, decentralized alternatives for water provision have a greater appeal as means to improve water access and quality, especially for lower-income and rural households, which are currently underserved.

El Salvador has aligned to the international agenda that seeks to guarantee basic rights for citizens, including the right to water. The country has aligned policy to the Millennium Development Goals (MDGs) and now to the Sustainable Development Goals (SDGs). Yet the right to water remains a disputed issue. The Special Rapporteur of the United Nations for the Right to Water issued a declaration urging the government of El Salvador to guarantee the right to water and sanitation, as well as reduce inequities in access.

Water scarcity will be one of the main challenges the country faces in the long run. It has already become an obstacle for economic growth, stalling investment in residential and industrial projects due to the inability to secure permits from the water authority. Rainwater harvesting represents an attractive alternative to secure water access for poorer and rural households. It is a renewable solution, based on natural cycles (UNESCO, 2018) with a high potential to solve in part the problems of lack of access, equity and to achieve sustainability, without requiring regulatory or administrative reform.

In this paper we estimate the feasibility of adopting rainwater harvesting systems (RHS) in El Salvador as a means to ensure sufficient and adequate water supply for residential use, especially for poor and rural households who are the targets of social policy, i.e., urban informal settlements and rural households in territories not served by current infrastructure (Jouravlev, 2004). We conduct a cost-benefit analysis of the adoption of RHS and other technical alternatives to improve water access, and we assess the impact on equity of adopting RHS in underserved households.

Section 2 provides a brief overview of the most pressing issues for the water sector in El Salvador, which are shared to some degree by many countries in the region. In Section 3, we discuss several alternatives for increasing water access and conclude that RHS have an important potential for households currently underserved. In Section 4, we set up a model to assess the performance of RHS in the context of El Salvador, taking into account the characteristics of households, rainfall patterns, geographic variation and different strategies for rainwater collection. We discuss the results for several scenarios in Section 5 and conclude with some implications in Section 6.

2. An Overview of the Water Sector in El Salvador

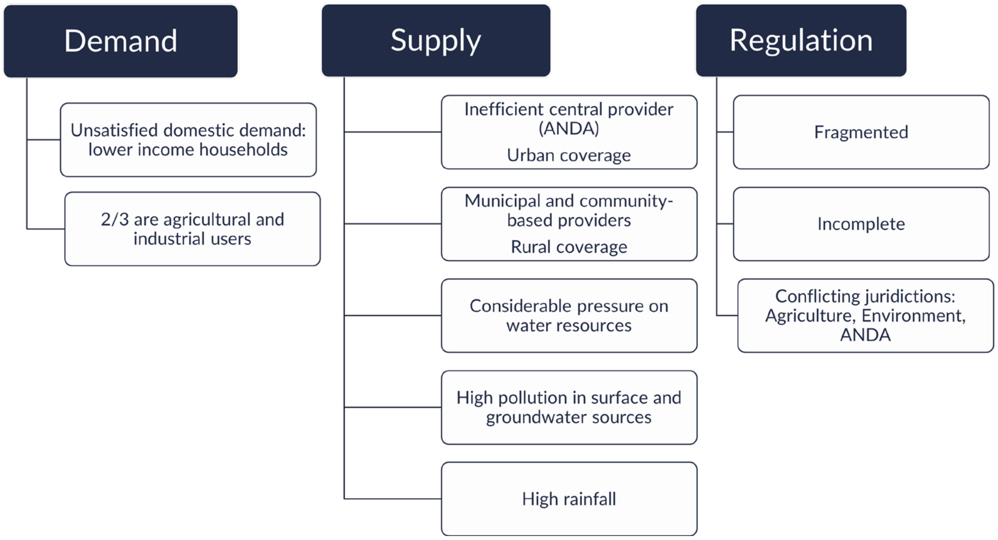
In El Salvador, discussions on the appropriate framework for regulating water and sanitation have been ongoing since 2001, with Congress unable to pass legislation on the issue. Water is a politically charged issue, and a large number of organizations defend the human right to water and promote absolute control of the government over water resources. The public debate has centered on the administration of resources, not on issues of quality and coverage of water services, or the sustainability of water usage.

One of the main reasons for the failure to create a functioning water market in El Salvador is the absence of a general Water Law that clearly specifies clearly the governance of the sector, establishes the place on the hierarchy and the responsibilities of each institution, and sets forth the instruments and incentives available to them. In the remainder of this section we present several important issues facing the water sector in El Salvador.

The main public provider for residential and business users is known as ANDA—the National Water and Sanitation Administration—which operates as a publicly owned autonomous entity. ANDA operates with large inefficiencies and lacks incentives to improve quality of service or operational efficiency. No significant investments have been made in improving water extraction capacity or maintaining transmission infrastructure, with the result that approximately 50 percent of water produced is lost through leakage (ANDA, 2018). Figure 1 summarizes the main issues pertaining to the water sector in El Salvador.

While ANDA is by far the largest water provider in the country, there are more than 2,300 community-based, municipal and private water providers for residential, commercial and industrial users. ANDA serves approximately 44 percent of households in El Salvador, while an additional 38.3 percent is served by smaller providers (rural water boards, municipalities and private providers) and 23.7 percent report no access (Dimas, 2010). Quality of service is poor, with most households receiving water for only a few hours, a few days of the week. The tariff structure of ANDA contains heavy subsidies for most users, while tariffs for other providers vary significantly. ANDA pays a subsidized price on electricity, increasing the amount of subsidy passed on to consumers, and most households pay less than a third of ANDA’s reported cost of production. The subsidy tends to be regressive, concentrating on the upper half of the income distribution, partly because poor households are not connected to the grid, or when connected, have lower consumption than richer households.

Figure 1. Relevant Issues and Variables in the Water Sector in El Salvador

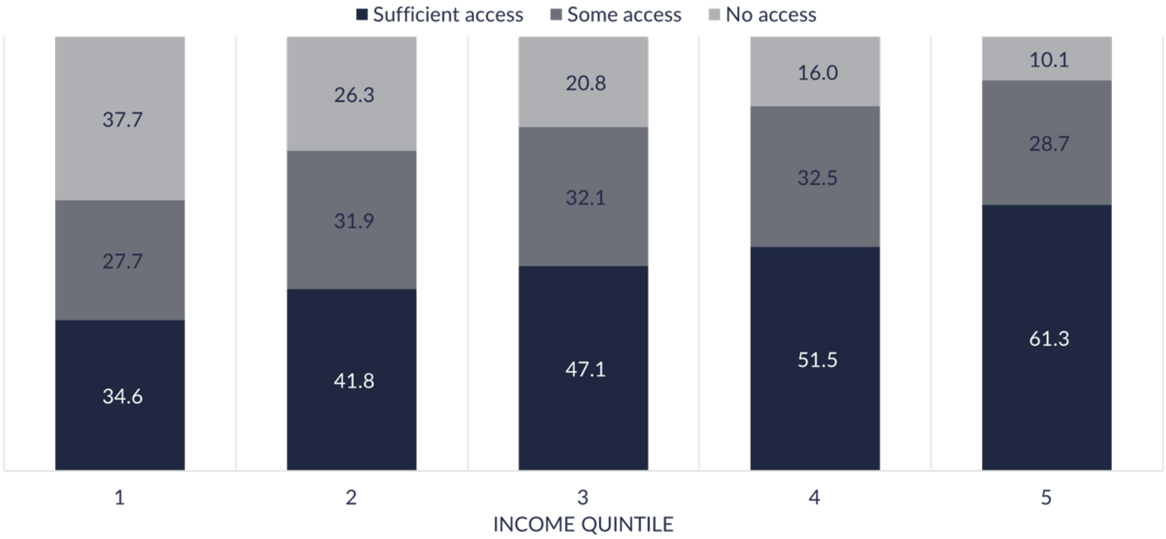


Source: Authors' compilation.

Access to water varies substantially by income level. Figure 2 shows that sufficient access is limited even for the highest income quintile, but that the share of households without access to an improved water source is much greater in the lowest quintile. We define sufficient access as having piped water for at least four hours per day, every day of the week. If the water service does not satisfy these conditions, we label it as "some access."

The water sector is poorly regulated, with some conflicting legislation and legal vacuums. A general water law has been under discussion since 2001, but conflicting special interests have presented the passage of legislation in Congress. Moreover, lack of investment and pollution have taken the country to the brink of hydric stress (CEPAL, 2015), even though rainfall averages 1,787 mm. (70 in.) per year—a substantial amount in regional terms—and surface and groundwater resources are still relatively abundant.

Figure 2. Access to Water in El Salvador, by Household Income Quintile



Source: Authors' calculations based on DIGESTYC (2017).

Water (both surface and underground) is considered a public resource in El Salvador, and ANDA has been protected from competition and granted free use of the resource. On the other hand, no efforts have been made to protect land which serves as recharge ground for underground aquifers. The resource is nowadays heavily contaminated, and aquifer levels are falling rapidly (MARN, 2017a). When conflicts over ownership of land rights arise, settlements are reached by civil courts on the basis of the right of the owner of the land to use water, ignoring effects on other users. Only water harvested from rainfall is exempt from public regulation, as specifically stated in the Law of Drainage and Irrigation, the main body regulating water use in the country.

Tariffs for residential, commercial and industrial water use do not reflect the capital cost of the water system, nor the externalities (pollution, permanent decrease of aquifer levels) imposed on other users. Thus, users do not have the adequate incentives to invest in technological measures that could reduce pollution and external effects to an efficient level, and sustainability in the use of the resource is not attained.

Water in El Salvador is treated with traditional, relatively inexpensive methods such as chlorination, sedimentation, coagulation, and filtration. Increasing pollution and natural presence of contaminants (heavy metals and mineral salts) in groundwater and surface water imply that nontraditional, more expensive technologies such as ozonation, reverse osmosis, micro and ultra-filtration should be used to purify water for human consumption (MARN, 2017a). However, public water providers lack the resources to build new and more expensive treatment plants and to cover increased operational costs.

In addition to the low access rate to potable water, treatment of wastewater and sewage is close to nonexistent. Slightly under 2 percent of wastewater is treated in primary facilities, and the rest is dumped untreated into streams or the ocean.

In summary, El Salvador presents a water market with fragmented provision, water extraction that is not systematically regulated, important challenges regarding coverage, quality and treatment, and the added difficulties of deforestation, urbanization, pollution and climatic change. Water market reform is politically difficult and focuses on control of resources. All these elements have a significant impact on deterring investment in agriculture, construction and new industry, and they pose an important obstacle for economic development, while precluding the protection of the human right to water for a significant share of both the urban and rural population.

In this context, the possibility of adopting rainwater harvesting systems represents an opportunity for a market solution that is implemented quickly and without the need to wait for a solution to all the regulatory issues of the water sector, while potentially achieving strong impacts on equity.

3. Alternatives for Expanding Water Coverage in El Salvador

3.1 Expansion of the Water Network

Increasing the number of households served by the water network involves significant investments. One option is for ANDA to expand its coverage to currently underserved urban and rural areas. Alternatively, the government could favor competition and allow other actors (private, community-based and/or municipal) to enter the water market.

Expanding ANDA's coverage would require a substantial overhaul of the institutional capacity of the largest public provider. Historically, ANDA has shown important inefficiencies in management, leading to a precarious financial situation (Pastrán, 2018) and low productivity. Expanding the water network entails significant investments from the public sector. An optimistic estimate of the cost of achieving nearly universal coverage is provided by Almendares, Avelar and González (2009), who suggest that an investment of $30 million per year for 22 years could achieve that objective, not taking into account aspects related to the complex topography of the country or increased demand on water sources.

Alternatively, decentralization and privatization of the water service could be undertaken, following the model of electricity distribution. Given the geography of the country and the characteristics of demand, the concession and regulation of regional monopolies may be a cost-efficient approach for universal coverage. A major obstacle is the position of most civil organizations involved in water regulation and policy, which are strongly opposed to any feature resembling privatization, and have engaged in a vigorous defense of the right to water (Ramos, 2017).

The feasibility of expanding the water grid, either through ANDA or private providers, lies in the sustainability of the extraction from underground aquifers and surface bodies of water, which are almost universally polluted and overexploited (MARN, 2017a).

3.2 Seawater Desalination

Desalination is considered another sustainable solution for the problem of producing water for domestic and agricultural uses (Gao et al., 2017). The feasibility of desalination is closely linked to the cost of energy and the interest rate. (IEA-ETSAP and IRENA, 2012; WateReuse Association, 2012; Papapetrou et al., 2017).

In relative terms, desalination is still an expensive alternative for low and middle-income countries like El Salvador (see Table 1). Initial investment is still high, although capital requirements have been decreasing over the years. Desalination has the potential to be a solution for specific projects, for instance financed by public-private partnerships. For the urban poor and rural households, however, desalination still has low potential due to the difficulty of recovering the cost of investment and the availability of alternative water sources (Abazza, 2012).

The feasibility index developed by Gao et al. (2017) suggests there are large differences across countries in terms of the potential to implement desalination for water supply. In countries like El Salvador, feasibility is low due to the availability of other resources, the lack of technological readiness and the cost of operating and maintaining desalination infrastructure.

Table 1. Feasibility Index for Desalination (desalination feasible if score greater than one)

Country	Fi 2015	Fi 2050
Argentina	3.09	4.71
Costa Rica	0.78	1.21
Chile	0.63	0.96
Brazil	0.62	0.94
Colombia	0.60	0.75
El Salvador	**0.22**	**0.28**
Honduras	0.04	0.06

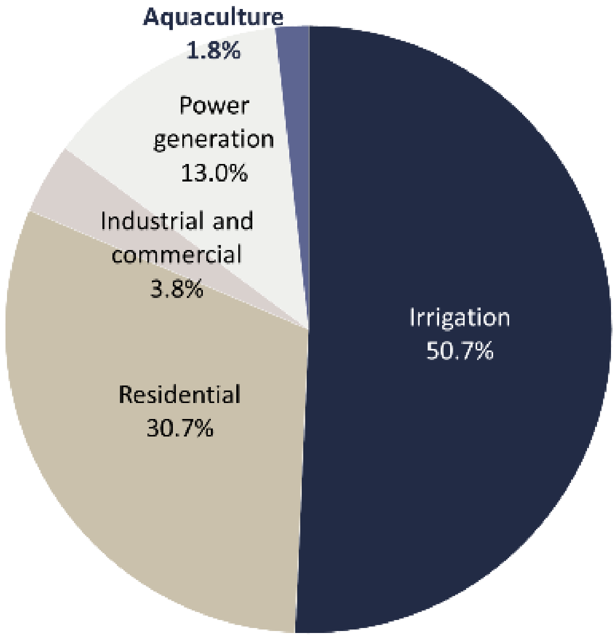
Source: Adapted from Gao et al. (2017).

3.3 Rainwater Harvesting Systems

Rainwater harvesting systems (RHS) have a significant potential in securing the provision of water for a group of the population that is harder to reach by traditional water networks, i.e., poor and rural households. RHS also hold potential as a source of water for agricultural uses (Amon, Rahman and Gathenya, 2016).

Official data (MARN, 2017b) indicate that little more than half of water extracted is devoted to agricultural uses (irrigation for pastures, sugarcane, maize and beans) and about 30 percent is extracted for residential use. Residential demand is expected to grow at a 1.5 percent annual rate from 2017 to 2022, according to the same source, while agricultural uses will increase at a 2.8 percent rate over the same period, greater than the growth of total demand, which is forecast at 2.1 percent per year.

Figure 3. Water Use by Sector in El Salvador



Source: Adapted from MARN (2017a)

Several papers have performed analysis of the economic feasibility of RHS, both in developed and developing countries. Papers that contain an economic analysis of RHS identify a number of costs and on water savings from tap water or other existing sources, while costs include electricity, treatment and operational costs, among others (Gabarell-Durani et al., 2014; Matos et al., 2015; Hall, 2013)

Some authors focus on environmental impacts of alternative technologies, as well as the varying costs of capital for each option (Mitchell and Rahman, 2006). Attention is also given to financial issues such as interest rates, inflation and the structure of water prices in each region (Morales-Pinzón, 2012).

Rainwater harvesting can be used for domestic purposes in five ways (Thomas and Martinson, 2007):

- As sole source of water, most often when there are no other alternative sources or where rainfall is abundant and constant over the year.

- As the main source of water, with alternative sources (of higher cost or less convenience) used during dry periods.
- As a wet-season source, because of cost-efficiency or adequacy.
- As a potable water-only source.
- As an emergency source of water.

Given the lack of convenient, low-cost alternative sources of water in the communities considered as target population in this paper, and the seasonal character of rainfall in El Salvador, we consider RHS as an alternative for a wet-season main source of water, in households without reliable water service from the water grid. The length of the dry season (six months) implies that domestic RHS cannot be an economically efficient source of water for the entire year, because that would require a catchment area and tank size beyond feasibility.

Several benefits are associated with the use of domestic RHS. The most significant are the following:

- Water savings from other sources, including piped water if available. These translate to monetary savings or a decrease in pressure for groundwater or surface water resources.
- An improvement in time use. Fetching water from a nonresidential water source involves significant time and effort, which falls mostly on women and children in the household.
- An improvement in the use of water: households located further from a nonresidential water source reduce water consumption in order to save time and effort, adopting lower hygienic standards.
- Avoiding the use of polluted local sources such as streams or surface wells. In several locations in El Salvador groundwater is not considered adequate for human consumption due to the presence of toxic minerals and/or fecal matter (MARN, 2017a)
- RHS are a decentralized, domestic water source and thus are less vulnerable to threats of infrastructure breakdown, contamination of external reservoirs or fluctuations in the cost of operation.

At the same, RHS have several potential drawbacks:

- Contamination from material accumulated in rooftops or gutters, including bird droppings and organic material.
- Airborne pollutants.
- Vulnerability to dry spells or drought.
- Failure due to inadequate maintenance and repair.

Risks from pollutants can be reduced by diverting first-flush, filtering and separation, although these increase the operational and financial requirements of RHS.

4. A Model to Assess Rainwater Harvesting Feasibility in El Salvador

A substantial number of communities in El Salvador are underserved by the national water administration (ANDA) and local water providers, either because they are not connected to the water grid or, even if connected, they do not obtain continuous water service. Rainwater Harvesting Systems (RHS) offer an alternative source of water for domestic (human and household consumption) and agricultural purposes. In this section, we build a model to assess the economic performance of RHS in the context of urban and rural households in El Salvador, against current and prospective sources of water for the household.

4.1 Model Objectives

We construct a water balance model and perform a cost-benefit analysis to assess the feasibility and economic viability of the adoption of RHS in El Salvador. We assess the economic performance of individual and communal RHS in several settings corresponding to particular groups of households without reliable water access in El Salvador. These settings correspond to the following groups:

- Rural households without access to piped water, currently obtaining water from points of access such as public standpipes or boreholes, either at close (less than 200 m.) or considerable distance (more than 200 m.) from a water access point.
- Urban households without residential access to piped water, but with access to standpipes within their community (at less than 200 m. from the household). These households tend to be poorer and have houses smaller than average.

- Small groups of 4-5 rural households representing typical nuclei in isolated communities, at considerable distance (more than 200 m.) from a water access point.

Data used to construct the model include the following features: characteristics of households targeted with RHS, the identification and the estimation of the cost of technological alternatives for RHS, the technical performance of RHS, the estimation of benefits, and financial and environmental parameters required for the estimation of the net value of RHS in each scenario.

Household characteristics are obtained from the Multipurpose Household Survey (known as EHPM) conducted annually covering all regions in the country. We are able to estimate household income, size, water sources currently in use and (when connected to the piped water system) water consumption.

4.2 Rainwater Harvesting Technology

To evaluate technological alternatives and determine parameters specific to the model, we employ rainfall data from records collected by the National Land Studies Service (SNET), which contain daily precipitation data for a number of years for different measurement stations distributed across the country. Catchment area (roof area) is estimated from average household size, which ranges from 27 to 60 square meters across different geographic areas and socioeconomic strata, so an average of 50 square meters is used (rural dwellings may be larger). Demand is estimated from the household survey, as well as parameters given by international literature.

Table 2. Modeling Data and Assumptions

Component	Description
Rainfall profiles	Used meteorological data from SNET with daily rainfall records for three representative locations in the country: San Salvador (inner plateau), San Miguel (eastern lowlands) and Comalapa (coast).
Type of RWH	Wet-season: an additional water source is assumed for most of the 6-month long dry season. Wet-day and year-round scenarios considered.
Catchment surface	50 square meters (modest one-floor house size, typical of urban poor communities, rural houses may be larger)
Runoff coefficient	0.9 (typical for metal roofs, fiber-cement and clay tile have lower coefficients)
Storage tank	Plastic (PVC) manufactured tank of different sizes available in the market (0.75, 1.1, 2.5 m3). Ferro-cement tank for larger sizes.
Filtration technology	Ceramic pot filter
Pump	Manual pump

Some assumptions related to technical or design parameters of RHS, including the runoff coefficient from catchment area (roofs), which is set at 0.9 reflecting the predominance of sheet metal roofs in target households (Thomas and Martinson, 2007), a 40 m2 catchment area equal to an estimated average size of a minimum housing solution (although smaller houses are found in urban areas, especially in massive low-cost developments, while rural houses tend to be slightly larger; see Harth, 2013). As for tank size, several alternatives are evaluated, from a smaller 0.75 cubic meter tank to a very large 40 cubic meter ferro-cement tank. In terms of the balance between cost and adequacy of supply, a 2.5 cubic meter tank is proposed as the best alternative for a domestic RHS.

Various other specifications for the RHS were considered, such as those involving water purification alternatives and materials employed, with selected alternatives indicated in Table 2. The capital cost of an RHS includes the cost of a rainwater tank, tank base, pump, electrical supplies (when an electrical pump is considered), leaf-eater device, connection devices, plumbing supplies and labor. The initial investment and operational cost of the RHS alternatives considered is constructed by using actual market costs for the different components of the systems (tanks, pipes and collection mechanisms, pumping alternatives, chemical reagents and filtration/purification devices). We define the operational life of RHS according to technical specifications of manufacturers or experts' opinions.

We assess some of the main technical issues regarding the choice of technology for rainwater harvesting, including water quality and treatment for drinking water, and then move to the economic assessment of RHS.

4.2.1 Water Quality

The choice of rainwater over other sources of water depends not only on its cost and effectivity, but also on aspects such as the quality of the water produced by RHS, compared to other sources. The quality of rainwater collected depends on the type of roofing and ambient conditions (weather patterns, air pollution), with some degree of variability across regions (Farreny et al., 2011).

Rainwater is relatively safe from contamination in the air, but dust and debris carried by the wind, leaves, bird and other animal droppings accumulated on roofs may contaminate water collected by RHS (Meera and Ahammed, 2006; Gikas and Tsihrintzis, 2012; Yaziz et al., 1989). The first wet-season flush is usually discarded because of the large amount of dust and organic material accumulated at the end of the dry season (Thomas, 1998). Simple dispositives may be used to divert first flush and avoiding contamination of storage tanks (Gikas and Tsihrintzis, 2012).

Rainwater is slightly acidic in all but the most industrially polluted areas, which gives it the ability to dissolve heavy metals and impurities from catchment surfaces and storage tanks. Rainwater usually satisfies the thresholds established by the World Health Organization for chemical substances in water (Lee et al. 2017; World Health Organization, 2005), and good quality can be guaranteed by the use of plastic or ferro-cement (thin-shell concrete) storage tanks, along with filtration systems if water is to be used for human consumption (Achadu, Ako, and Dalla, 2013).

In general, the physicochemical quality of rainwater collected from rooftops is greater than surface and groundwater (Farreny et al., 2011; Lee et al., 2017). The risk of contamination is significantly reduced with simple measures that final users may learn with short training.

4.2.2 Water Treatment for Human Consumption

Table 3 shows a comparison of several rainwater treatment systems for human consumption, following the guidelines of the World Health Organization (RAIN Foundation, 2008; World Health Organization, 2002). Appropriate options from the technological standpoint include chlorination, which removes bacteriological contaminants but modifies water taste and requires training to use adequate amounts to purify water for human consumption. Boiling water is adequate in terms of purification and is a less demanding option on the user, but it requires fuel expense.

Table 3. Comparison of Alternative Methods of Water Purification

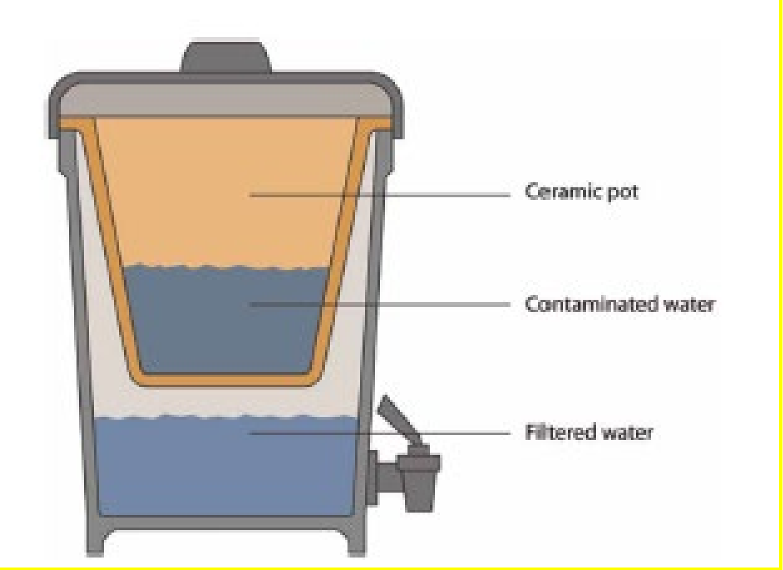
Method	**Bacteria removal efficiency**	**Virus removal efficiency**	**Effect on taste**	**Main purpose**	**Type of water**
Chlorination	High	High	Yes	Disinfection	Clear
Aluminium sulphate	High	High	No	Enhances flocculation and precipitation of flocks	Turbid
Ceramic pot filter	High	Moderate	No	Filtration and disinfection	Turbid and clear
Bio sand filter	Moderate	Moderate	No	Filtration	Turbid and clear
Boiling	High	High	No	Killing bacteria with heat	Turbid and clear
SODIS	High	High	No	Killing bacteria using UV radiation	Clear

Source: Authors' compilation based on RAIN Foundation (2008) and World Health Organization (2002).

Our selected choice is a ceramic pot filter (Figure 4), which offers adequate water purification without altering taste and has a much lower cost than other alternatives over the lifecycle of an RHS. There is no fuel or energy use since the filter works by gravity. Although higher-cost commercial versions exist, the cheapest alternatives may cost as low as US$10 per household, with a US$4 annual expenditure of a replaceable filter element.

Other purification alternatives—shown in Table 3—offer adequate disinfection properties but require the use of more expensive commercial products and/or greater user training and maintenance, which reduces its viability in poor households.

Figure 4. Ceramic Pot Filter System



4.2.3 Water Catchment

The rainwater harvesting system proposed is collecting runoff from rooftops. The system has three main components: a collection surface, guttering and a storage tank. The use of hard roofing materials allows the collection of a significant amount of total rainfall, and its cost is not usually included in the evaluation of RHS (Thomas, 1998). Guttering is required to intercept rainwater and transport it to the storage tank, for later use. We assume no guttering is installed and estimate its cost using market prices for building materials. We assume the storage tank is located at ground level, so no additional expenses on installing an elevated or underground tank are required.

An advantage of collecting rainwater is that water is collected and stored at the point where it is used, eliminating the need for expensive and complex distribution systems (Krishna, 2005).

There are several storage strategies in RHS (Thomas, 1998). One is wet-day, where rainfall is almost daily and storage is limited to about one to three days of consumption. The wet-season approach implies storage for three to ten days of consumption, to ensure supply during the wet season. Year-round storage is required if the RHS is the sole source of water for the household. Since the storage tank is the main part of the cost of an RHS, a cost-benefit assessment must be performed in order to choose an efficient tank size. Table 4 shows the minimum tank size required in each strategy for a four-person household, and approximate costs.

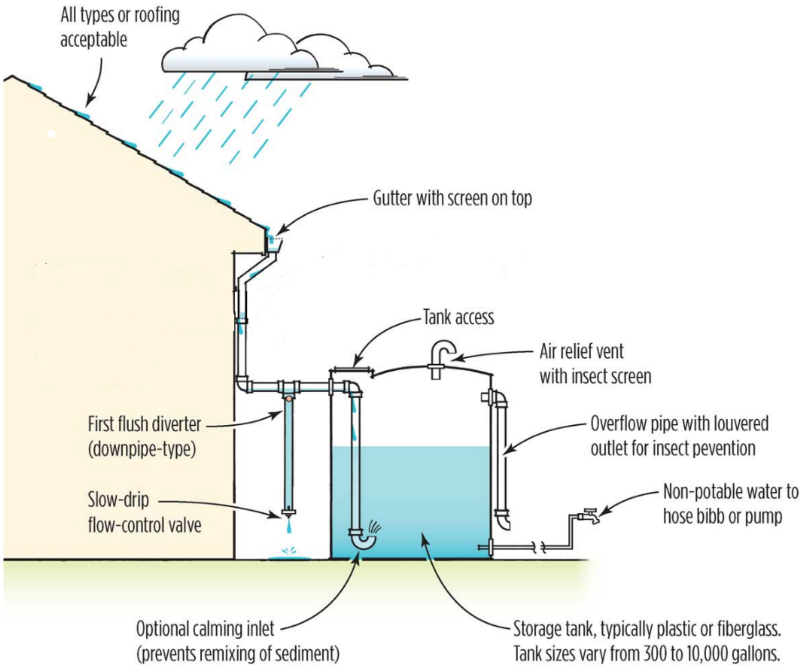
Table 4. Rainwater Storage Strategies and Required Storage Tanks

Strategy	Wet-day	Wet-season	Year-round
Tank size required in m3, assuming 40 m2 catchment surface	0.40 (2 days of consumption)	2.5 (12 days of consumption)	40 (200 days of consumption)
Approximate tank cost (market price c. 2018)	US$50	US$191	US$3,000

Tank sizes lower than 2.5 m3 made from PVC are available in the market. A 36 m3 tank, required for year-round supply, would have to be built in situ and made of ferro-cement or brick and mortar (the first option being cheaper). A 36 m3 tank would require a large space, of about 18 m2 or a circle with a radius of 4.8 m.

Figure 5 shows a typical rainwater harvesting system. The rooftop constitutes the collection surface. Water runs to gutters and passes through a coarse screen to retain solid objects washed from the rooftop. Water then flows through downpipes, which include a system to divert first flush that contains contaminants collected over the dry season. Finally, water reaches a storage tank, which must be cleaned periodically and kept closed to avoid the growth of algae and mosquitos. An overflow pipe and ventilation are required for the tank. Optional components include a calming inlet to avoid the remixing of sediment inside the tank

Figure 5. Schematic Representation of a Rainwater Harvesting System



Source: Roof rainwater harvesting system (https://www.watercache.com/rainwater/residential).

4.2.4 Rainfall Patterns

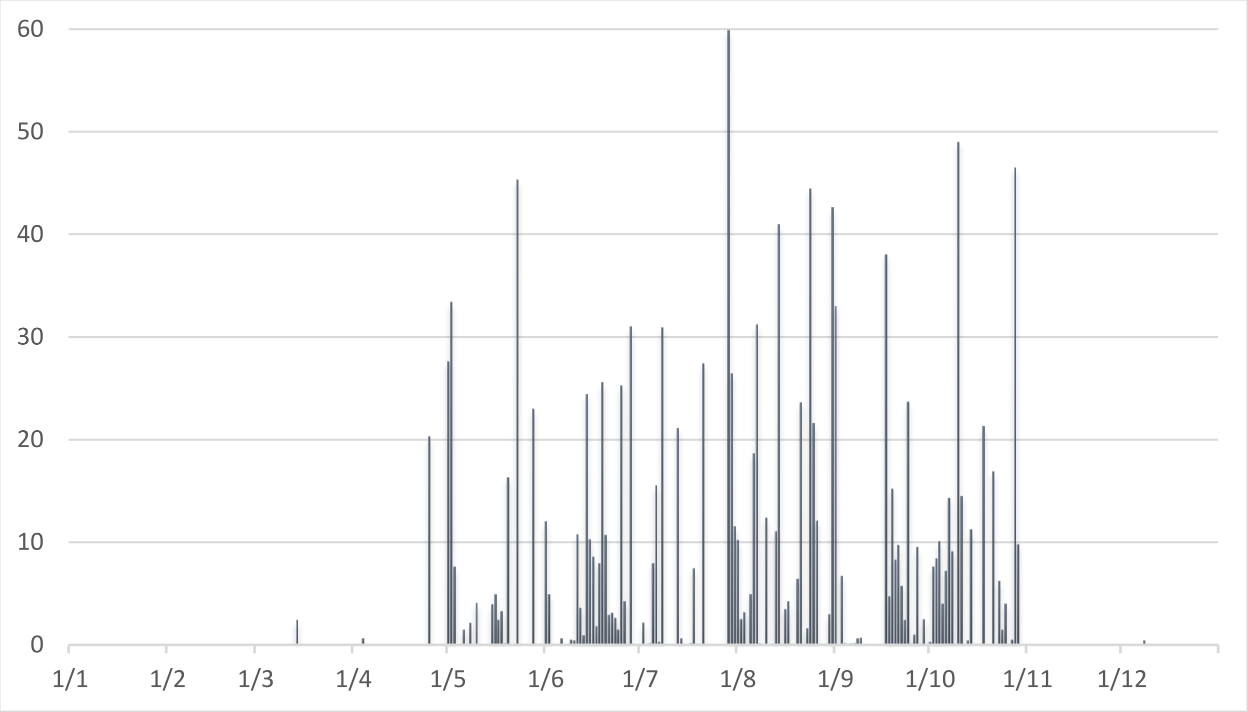
We obtained data for daily rainfall for three locations in the country that represent the average and lower extremes in terms of rainfall amount and variability. The station at San Salvador, located on the central plateau, represents average rainfall, while Comalapa station, located on the coast, represents higher-than-average rainfall and San Miguel station, in the drier eastern part of the country, represents the lower bound in precipitation. Table 5 shows the different rainfall scenarios used in the model. The most representative data are those from San Salvador, typical of the majority of the central areas of the country, which are also the most populated. San Miguel represents most of the eastern lowland areas of the country, as well as some drier areas in the western fringes of the country. Comalapa is representative of the coastal areas, which experience intense precipitation but fewer rainy days. Mountainous areas in the coastal ranges and northern border have greater precipitation, so any positive results valid for other areas should hold for those areas as well. (See the map in Annex 1 for additional details on rainfall).

Table 5. Parameters Assumed in the Estimation of the Economic Performance of RHS in El Salvador

Station	Total rainfall (mm)	Rainfall days	Average rainfall per day (mm.)
San Salvador	1,566.3	134	11.7
Comalapa	1,751.8	114	15.4
San Miguel	1,307.8	112	11.7

Rainfall in El Salvador is concentrated in the six months from May to October, with very little precipitation in the dry season running from November to April. The wettest months are June and September, and in some years a dry spell of two or three weeks may be experienced in the last half of July or the first weeks of August. Figure 2 shows daily rainfall for the driest station (San Miguel)

Figure 6. Daily Rainfall Data for San Miguel Station, 2017



Source: Authors' calculations based on SNET rainfall data.

4.3 Financial Modeling

Financial variables include the cost of capital, which is set to the standard interest rate of 12 percent used for the evaluation of social projects in Latin America (Campos, Serebrisky and Suárez-Alemán, 2016), as well as an alternative rate of 8 percent considered in some projects. As a benchmark, from the household standpoint, interest rates available for microloans in small communities may be significantly higher, in the range of 25-50 percent per year. We report estimates of private viability using the interest rate of 12 percent. Other financial aspects to consider include the cost of electricity (or the value of time required to operate manual pumps). We project all estimates in constant USD, at 2018 prices.

We employ market prices for materials and equipment, including storage tank, water pump, pipes and gutters. These prices represent the best prices obtained from large retailers in the country and do not include sales tax.

4.4 Model Setup

4.4.1 Benchmarks

A model of economic performance compares the availability of water and the cost of obtaining water for alternative sources. We consider the following policy alternatives to the development of an RHS:

- The purchase of water from commercial providers (water tankers for general use and bottled water for drinking).
- The construction of common access points at the community level (at an average of 200 m. from households, by drilling a well or borehole to access the water table.
- The expansion of the water supply network, assumed to involve an extension of 2 km. from rural communities and of 200m. from urban communities.

Table 6 shows the parameters assumed in the estimation of the economic performance of each alternative. These include the costs, useful life, time required per household and demand covered by different alternative forms of water provision for households.

Table 6. Parameters Assumed in the Estimation of the Economic Performance of RHS in El Salvador

Parameter	RWS	Water tanker	Water transport	Network expansion
Cost per cubic meter	n.a.	\$5.00 - \$7.50 (urban) \$10.00 (rural)	n.a.	\$0.80
Fixed cost	\$524 (2.5 m3 tank)	\$50 (water storage barrel)	n.a.	\$1,500.00
Useful life	45 year	n.a.	n.a.	60 yr.
Time spent per household per day	0	0.5 hour	1 hour- 2.5 hour	0
Quality of water	Potable (with filtration)	Non-potable	Potable (depending on the source)	Potable
Other costs		Boiling or filtration to make potable	Boiling or filtration if source not potable	

4.4.2 Demand

We use rainfall data combined with several assumptions on water demand to estimate the quantity of water provided by an RHS and several estimators related to the adequacy of coverage.

Demand assumptions include the amount of water used per person, which is set at two values: 20 liters per day per person as a minimum for essential uses (drinking and cooking), as well as 50 liters per day per person for other uses. These values are mentioned by the World Health Organization and discussed by Howard and Bartram (2003). With 20 liters per person, a household should be able to satisfy drinking, food preparation and basic hygiene needs, whereas 50 liters should provide for cleaning, laundry and personal hygiene. The average household is assumed to have four members, based on DIGESTYC (2018)

Benefits to the household include a reduction in water consumption (if connected to the water grid or purchasing water from other source, such as water tankers) or in the value of the time required to fetch water from common sources such as public wells, standpipes or natural sources such as rivers and springs. We compare the cost of water obtained through RHS with the market price of water purchased from water trucks.

The cost of water obtained from rain harvesting may be compared to that of water from the water grid, although this comparison must be viewed with caution because the price of the latter does not adequately reflect its opportunity cost, given that the government-owned water company does not recover capital or financial cost from user fees and employs subsidized inputs (electricity).

4.5 Model Specification

We construct a simple daily water balance model to estimate the coverage of water needs in three locations in El Salvador, which represent the limited climatologic variation within the country. Rainfall ranges from 1,300 to 1,750 mm. per year, and the rainy season runs from late April or early May to the end of October. Using daily rainfall data, we project the amount of water collected by the RHS, the amount used by the household and thus, the percentage of water needs that are satisfied by the system.

A number of operational indicators are used, in line with the literature. They include no water days (NWD), which indicates the number of days the system cannot provide water for the household because the tank is empty, and the rainwater usage ratio or RUR, which indicates the relative efficiency of the system, measured by the percentage of collected rainwater that is actually used by the household. Other operational parameters used in some of the literature (Mun and Han, 2012) are water-saving efficiency (WSE), which measures the percentage of water demand supplied by the RHS, and the cycle number (CN), which shows the proportion of total rainwater use to tank volume.

The water balance model is defined by equation (1)

$$V_t = V_{t-1} + Q_t - Y_t - O_t \qquad (1)$$

where V_t is the water volume stored at the tank at time *t*, Q_t is the amount of water collected at time *t*, Y_t is the rainwater used for household purposes and O_t is the overflow amount.

Operational parameters are calculated as follows:

$$NWD = \frac{T - \sum_{t=1}^{T} WD}{T} \times 100 \qquad (2)$$

$$RUR = \frac{\sum_{t=1}^{T} Y_t}{\sum_{t=1}^{T} Q_t} \times 100 \qquad (3)$$

where *WD* is the number of days with water provided by the RHS and *T* is the total number of days considered (in this case, the full year)

5. Results

We present results for the following cases:

- Wet-day, wet-season and year-round accumulation strategies.
- All uses (50 liter per person per day) or basic uses (20 liter per person per day) utilization of rainwater
- Three locations within the country: Comalapa, San Salvador and San Miguel.

For each case, we compute the amount of rainwater collected and used, the number of days without water from rain harvesting, the percentage of demand satisfied and the cost of rainwater and of providing water to the household (from rainwater and water purchased from water trucks).

Results are summarized in Tables 8 and 9. For all household uses, tank sizes of 0.75, 2.5 and 40 cubic meters minimize costs for the strategies of wet-day, wet-season or year-round supply of rainwater. For year-round supply, a larger roof catchment area is needed. A four-person household would require a 60 square meter catchment area to ensure a year's supply of water from rainwater harvesting.

Table 8. Annual Performance of an RHS Installed on 50 m2 and 60 m2 Roofs, for a Demand of 50 lt. per Person per Day (covers all domestic uses)

	Wet-day strategy			Wet-season strategy			Year-round strategy		
	Comalapa	**San Salvador**	**San Miguel**	**Comalapa**	**San Salvador**	**San Miguel**	**Comalapa**	**San Salvador**	**San Miguel**
Roof size (square meters)	50	50	50	50	50	50	60	60	60
Tank size (cubic meters)	0.75	0.75	0.75	2.5	2.5	2.5	40	40	40
Collection capacity (m3)	78.8	70.5	58.9	78.8	70.5	58.9	94.6	86.3	76.5
Water used (m3)	32.1	34.1	32.5	37.9	38.4	39.9	73.0	73.0	73.0
Water-saving efficiency (% of demand covered)	40.7	46.7	44.5	52.0	52.7	54.6	100.0	100.0	100.0
No water days (%)	59.1	56.7	58.9	49.0	48.0	46.0	0	0	0
Rainwater usage ratio (% of catchment)	40.7	48.4	55.2	48.1	54.5	67.7	77.2	86.3	95.4
Cycle number	42.8	45.4	44.5	15.2	15.4	15.9	1.8	1.8	1.8
Rainwater cost (USD per m3)	2.05	1.93	2.02	2.06	2.03	1.96	5.22	5.22	5.22
Purchased water cost (USD per m3)	10	5	7.5	10	5	7.5	10	5	7.5
Average cost per m3 (USD)	6.50	3.56	5.06	5.88	3.44	4.47	5.22	5.22	5.22

Table 9. Annual Performance of an RHS Installed on a 50 m2 Roof, for a demand of 20 lt. per Person per Day (basic domestic uses)

	Wet-day strategy			Wet-season strategy			Year-round strategy		
	Comalapa	San Salvador	San Miguel	Comalapa	San Salvador	San Miguel	Comalapa	San Salvador	San Miguel
Roof size (square meters)	50	50	50	50	50	50	50	50	50
Tank size (cubic meters)	0.75	0.75	0.75	2.5	2.5	2.5	15	15	15
Collection capacity (m3)	78.8	70.5	58.9	78.8	70.5	58.9	78.8	70.5	58.9
Water used (m3)	16.4	16.8	16.4	20.4	20.3	20.2	29.2	29.2	29.2
Water-saving efficiency (% of demand covered)	56.2	57.4	56.2	69.8	69.4	69.2	100.0	100.0	100.0
No water days (%)	42.7	41.4	42.7	29.3	29.3	29.9	0	0	0
Rainwater usage ratio (% of catchment)	20.8	23.8	27.9	25.9	28.7	34.3	37.0	41.4	49.6
Cycle number	21.9	22.3	21.9	8.2	8.1	8.1	4.9	4.9	4.9
Rainwater cost (USD per m3)	4.00	3.92	4.01	3.84	3.87	3.88	9.38	9.38	9.38
Purchased water cost (USD per m3)	10	5	7.5	10	5	7.5	10	5	7.5
Average cost per m3 (USD)	6.63	4.38	5.54	5.70	4.21	5.00	9.38	9.38	9.38

The results show that RHS are capable of satisfying all water needs of a household during the rainy season but are very limited during the dry season. With a very large tank (of at least 40 cubic meters), stored water could cover demand for the entire dry season, at the cost of a significant investment and a large space requirement (the size of a large room of 4x4 meters).

Results are very similar across the country. For the wet-day strategy, RHS perform better in San Salvador due to the larger number of rainy days. For a wet-season strategy, the driest area, San Miguel, performs better, which is due to a greater spread of rainy days, even if total rainfall is the lowest.

To assess the economic performance of RWS, we compare them to a number of alternatives over the life cycle of the investment. We do so by computing an average cost of a cubic meter over the useful life of each alternative and comparing across alternatives. A similar analysis is performed by Amos, Rahman and Gathenya (2016).

The cost of rainwater harvesting is estimated per cubic meter, computing the annual amortization for the project with an interest rate of 12 percent, plus maintenance costs of $5 per year and the replacement of filtration every two years, replacing gutters and downpipes, including accessories, at two-thirds of the useful life of the project (year 30). The estimated cost per cubic meter is very sensitive to the interest rate used (12 percent in our estimations).

We estimate the cost of fetching water from a local point of access as the value of time employed in transporting water, which is estimated at 2 hr. per day for 200 lt. when the household has a close source and at 4 hr. per day when the source is further away. The value of time is estimated at the minimum wage rate of $1.5625 per hour. A cubic meter of water requires 10 hr. of transportation on average where the access point is close and 20 hr. when it is further away. Thus, a cubic meter may cost from $15.62 to $31.25 depending on distance from the access point.

Purchased water from water trucks may have different prices depending on distance from water sources and the availability of providers. In urban and peri-urban communities where the water service is unreliable or where there is no connection to the main grid, water is sold from at prices from $1.00 to $1.50 for a 200-liter barrel, or $5.00 to $7.50 per cubic meter. In rural areas, prices may be much higher, depending on distance and accessibility. We estimate an average of $10.00 per cubic meter, based on the assumption that more isolated, poorer communities do not resource to water tankers due to high cost and unavailability of providers.

The average cost of expanding the water grid is provided in Table 10, as estimated by Almendares et al. (2009), but this may in practice vary significantly across communities, since the cost of digging a borehole or connecting to the main distribution system will depend on topography, as well as on the depth of the water table, the possibility of connecting pumping stations to the electrical grid and the scale of the project. In general, the expansion of the water grid is an expensive option, costing a few thousands of dollars per household. For a community of about 200 households in a rural area, we use as lower bound the cost of connection estimated by Almendares et al. (2009) of $1,500 plus annual maintenance and operation costs.

Table 10 shows the results of the economic performance of each model. Clearly, RHS are the most cost-efficient water source. However, since RHS are able to supply water for only half of the year, they must be combined with some other source. We consider purchased water because is the most efficient alternative for the household and many, especially in urban and peri-urban areas, already use this source of water. Even when combined with purchased water, RHS is the most cost-efficient alternative.

Table 10. Cost per Cubic Meter by Alternative

	San Salvador	Comalapa	San Miguel
Rainwater harvesting	$2.03	$2.06	$1.96
Purchased water	$5.00	$10.00	$7.50
Expansion of water grid	$6.30	$6.30	$6.30
Water fetched from a close source (less than 500 m.)	$15.62	$15.62	$15.62
Water fetched from a source at more than 500 m. from household (4 hr. for 200 l)		$31.25	$31.25
RHS plus purchased water (average per m3)	$3.45	$5.93	$4.52

While Table 10 shows point estimates, however, the true cost of connecting to the water grid and/or fetching water from a nearby access point will vary significantly from one community to the next. In some cases, the cost of expansion of the grid will be less than that of using a combination of an RHS and some other source. RHS may also be appealing as a means of reducing consumption from the grid, especially for community-based networks where capacity is limited, and in the case where water fetching is the most economical alternative (if the source is very close to the household), to prevent the use of polluted water from streams or wells.

The estimated cost of RHS-sourced water is higher than the average of water tariffs for the region, which are \$0.54 for Latin America or \$2.07 if the Caribbean islands are included (IBNet Tariffs Database, 2019). However, with subsidized tariffs and greater availability of water across the region, tariff averages may not provide an appropriate benchmark for the adoption of RHS. The greater potential for adoption lies, however, in rural households where the expansion of the water grid is costly and where other solutions, such as boreholes plus local distribution systems, are not easily implemented.

5.1 Community-Based Rainwater Harvesting Solutions

We have examined the economic feasibility of RHS as independent domestic solutions, serving only one household. However, some efficiency gains may be attained by using RHS as a community-based solution implemented for a small number of households. The advantages of this approach include the following:

- More equity in access to water, since catchment areas vary across households, households with smaller rooftops may have access to an additional amount of water.
- Savings in capital costs. Individual tanks have a higher cost per cubic meter when compared with shared systems.
- The work of building larger tanks, made of ferro-cement,
- Sharing the work of maintaining gutters and downpipes clean and diverting first-flush.

There are important economies of scale in the construction of water tanks. For instance, while a 15 cubic meter tank is required to meet basic water needs for the whole year for a household, which has a cost of USD 2,000, a 60 cubic meter tank used by four households would cost about USD 3,800, implying savings of 50 percent in capital costs. Although additional expenses in installation and piping are required, these are insignificant when compared to savings in storage tanks, especially if the community provides labor required for the construction of the tanks and the installation of the catchment system. A shared system permits a 39 percent reduction in the cost per cubic meter (when year-round supply for basic uses is considered). For a wet-season strategy, though, the cost is approximately 8 percent higher because the system must use ferro-cement tanks, which are slightly more expensive than plastic tanks at this level of capacity.

Table 11. Performance of Shared RHS for Four Households, Basic Water Uses (20 liter per person per day), Year-Round Strategy

	Wet-season strategy			All-year strategy		
Component	**Comalapa**	**San Salvador**	**San Miguel**	**Comalapa**	**San Salvador**	**San Miguel**
Roof size required (square meters)	200	200	200	200	200	200
Tank size (cubic meters)	5	5	5	60	60	60
Catchment	315.32	281.94	235.40	315.3	281.9	235.4
Water provided	76.8	76.2	76.0	116.8	116.8	116.8
Water-saving efficiency	65.7	65.3	65.0	100.0	100.0	100.0
No water days	123	125	125	-	-	-
Rainwater usage ratio	24.3	27.0	32.3	37.0	41.4	49.6
Cycle number	15.4	15.2	15.2	1.9	1.9	1.9
Rainwater cost (USD per m3)	4.21	4.24	4.26	5.74	5.74	5.74

5.2 RHS for Households Already Connected to the Water Grid

Given the cost of about $2.05 per cubic meter from RHS, which is greater than ANDA's own estimate of production costs of $0.83 per m3, it would seem unfeasible to adopt RHS in areas already served. However, a significant number of households (20 percent of the population) are connected but lack reliable service, receiving water for less than four hours per day or experiencing long spells without water service due to ANDA's low capacity. The adoption of RHS would help to decrease water demand from ANDA, allowing the institution to provide water to underserved households, and would help these households to meet demand needs when the water service becomes unreliable.

We estimate that for households that must purchase more than 16 cubic meters during the rainy season and weeks immediately following, RHS is a more economical alternative than purchasing water. From another standpoint, if RHS may serve at least 22 percent of annual demand, installing a system is economically feasible. An added advantage is that water collected through RHS will have better quality than water purchased from water trucks, which is often sourced from polluted natural sources, often contaminated with wastewater, heavy metals and organic matter.

5.3 Equity Considerations

An important issue when considering the introduction of RHS is an improvement in water access for low-income and rural households, which are currently underserved in the water grid (Table 12). We show how access to RHS improve water access for vulnerable households (rural and/or poor), as well as the effect on their disposable income after investing in rainwater harvesting.

Table 12. Access to Piped Water in El Salvador (percentage of households), 2017

Urban		Rural	
Poor	**Nonpoor**	**Poor**	**Nonpoor**
79.9	90.7	56.0	64.2

Source: DIGESTYC (2018).

Access to water is inequitable in El Salvador, with the majority of households without access to piped water in the lower income quintiles, according to the multipurpose household survey of 2017 (DIGESTYC, 2018). For instance, in urban areas 26 percent of first quintile households lack access to piped water, while only 5.9 percent of fifth quintile households do. On the other hand, access to continuous piped water service is limited for all quintiles. While only 36.1 percent of first quintile households have full access to water, in the upper quintile the access rate is still only 49.3 percent.

In rural areas, access rates are less differentiated across income quintiles. While 43.7 percent of poorer households lack piped water, 32.5 percent of upper quintile households also lack access to the water grid. Full access to water ranges from 21.5 percent to 22.5 percent of households across all quintiles. Rural households are poorer in general, so the lack of access to water in rural areas reflects the poor's relative deprivation in this domain.

For 43 percent of households, access to water is partial, ranging from receiving water a few hours every day to receiving water just a few days of the week, for only a few hours. Following national statistical practice, we define adequate access to water when a household receives the service for at least three days per week, during at least four hours, which allows members to fill deposits and have enough water for everyday use. Some 61.2 percent of all households in the country satisfy this criterion.

For a poor urban household purchasing 12 cubic meters of water per month, the adoption of an RHS could mean savings of $35.40 per month during the rainy season (6.5 months), or $230.10 per year.

Investment in domestic RHS can have a significant impact in improving relative outcomes across the income distribution, since lack of access to water is concentrated in poorer households, even if it affects all income levels. This creates a double opportunity: to promote commercial solutions for rainwater harvesting for the upper part of the income distribution, who suffer from irregular water service, while developing subsidized or focalized interventions for the adoption of RHS in lower income households.

6. Conclusions and Policy Implications

Domestic rainwater harvesting systems offer an economically feasible and environmentally adequate solution for water access in El Salvador and other countries in the region. This is especially true for underserved communities in rural areas or where the cost of acquiring water is high relative to household incomes. Due to climatic factors, RHS are more easily implemented as wet-season solutions, useful during the rainy season, which lasts six months in El Salvador. Although year-round supply is feasible using RHS, this requires a larger capital investment, which may be efficient in very small or remote communities where other options (water transportation, local distribution systems) are unfeasible.

RHS are attractive as well because of better quality of water collected and the possibility of reducing demand on already stressed water grids. Capital costs of RHS are low when compared with expanding the water network or developing local water systems from wells or boreholes. Operating costs are much lower than the cost of fetching water from sources at some distance from the household or purchasing water from commercial providers. The latter two options also represent lower-quality options than RHS.

RHS have the potential to improve equity in access to water, since poorer and rural households suffer from lower access to the water network and lower quality of service. Unlike large infrastructure projects, which require financing from the central government, usually through public debt, RHS systems may be financed and implemented at a decentralized level, offering a quick response to the lack of water access for some populations in the region.

If a basic level of access for the entire year is to be provided, RHS are more cost-effective if implemented at a communal level, pooling groups of four households and reaching scale economies in storage tank costs. This strategy promotes greater equity in access to water when catchment areas vary between households.

Even if low, capital costs from RHS represent a significant investment from the point of view of poor households, and lack of property titles may be a disincentive to invest in house improvements. Thus, the provision of affordable credit or subsidization of capital investments for RHS may be required for widespread adoption. Partnerships with institutions already developing housing solutions (such as Habitat for Humanity and Techo among socially-oriented initiatives) may also help in the adoption of this solution among target households.

Current water tariffs are subsidized in several countries in the region, including El Salvador. The resources currently subsidizing the consumption of households with better incomes could be redirected for the subsidization or financing of RHS in underserved households, promoting a more equitable distribution of welfare.

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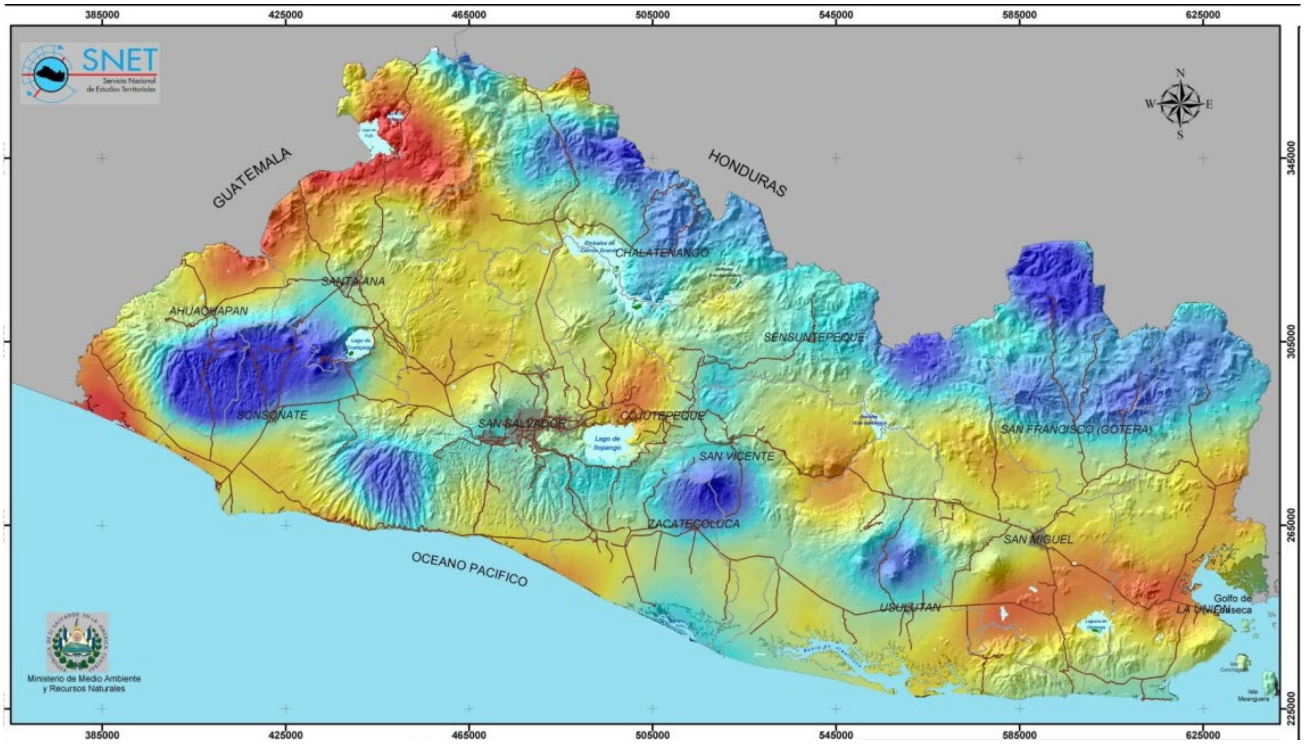
Annex 1. Rainfall Map for El Salvador, 1961-1990



Source: SNET (2002)
Notes: Dark blue shaded areas indicate more than 2,000 mm. per year; light blue: from 1,500 to 2,000 mm. per year; yellow and red: less than 1,500 mm per year.