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USE OF RAINWATER FROM ROOFS FOR HOME USE TO REDUCE WATER DEMAND IN REGIONS OF CHILE

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The climatic and water variations and effects caused by climate change generated a significant water deficit in the north and center of Chile, especially in periods of drought for more than 13 years, which is projected unfavorably in the future. short term. The considerable variations in rainfall in the country have been notable in the decrease in river flows, which has a direct implication for human use and consumption. This research has the purpose of evaluating the feasibility and importance of integrating of a rainwater harvesting system through roof coverings and the use of this to contribute to domestic family consumption and the reduction of water demand in all regions. The results obtained regarding the feasibility of a rainwater harvesting system that can be compensated in its initial investment in the medium and short term, added to a decrease in family consumption of the regional and drinking water network, yields good results. this being considered only the largest city of each of the regions.

Keywords: water deficit; climate change; use of rainwater; covers and roofs

APROVECHAMIENTO AGUA DE LLUVIA DE TECHOS PARA USO DOMICILIARIO PARA LA REDUCCIÓN DE LA DEMANDA HÍDRICA EN REGIONES DE CHILE

Las variaciones y afectaciones climáticas e hídricas producidas por el cambio climático generaron un importante déficit hídrico en la zona norte y centro de Chile, sobre todo, en los periodos de sequía desde hace más de 13 años, el cual se proyecta de manera desfavorable en el corto plazo. Las variaciones considerables de las precipitaciones del país han sido notables en la disminución de los caudales de los ríos, lo que tiene una implicancia directa por el uso y consumo humano. Esta investigación tiene la finalidad de evaluar la viabilidad e importancia de la integración de un sistema de captación de aguas de lluvia a través de cubiertas de techumbres y el aprovechamiento de esta como aporte al consumo doméstico familiar y a la disminución de la demanda hídrica de todas las regiones. Los resultados obtenidos en cuanto a la viabilidad de un sistema de captación de aguas lluvias que pueda ser compensado en su inversión inicial a mediano y corto plazo, agregado a una disminución del consumo familiar de la red de agua potable y regional, arroja buenos resultados, esto siendo considerada solo la ciudad más grande de cada una de las regiones.

Palabras clave: déficit hídrico; cambio climático; aprovechamiento de agua de lluvia; cubiertas y techumbres

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1. Introduction

The temporal and spatial variability of rainwater quality and the relatively small number of tests make it difficult to make a preliminary assessment of its economic exploitation. Determining the relationship between rainwater harvesting conditions and location and rainwater quality helps to indicate the range of options for rainwater use and parameters that require improvement (Zdeb, M. 2020).

Climate change presents significant uncertainties in future access to safe water, especially in rural communities facing water insecurity (Kisakey, V. and Van der Bruggen, B. 2018).

Liu et al. (2020) and Mejonnen and Hoeskstra (2016) state that the risk of water crises is a severe element of global concern and that the COVID-19 pandemic has reinforced awareness that underestimating the dangers of natural and global hazards can lead to irrecoverable adverse effects on the Earth, ecosystem, and society.

For their part, Wang, et al. (2018) and Christensen et al. (2007) indicate that the water crisis is even more difficult in developing countries in arid/semi-arid regions, where climate change can form zones of various climates with a high frequency of droughts and precipitations. In addition, they point out that population growth, urbanization, and industrialization can multiply the pressure of water scarcity in that semi-arid zone.

Orlińska-Woźniak, P. (2013) notes that approximately 36% of the world's population faces a water crisis. In many areas, it is impossible to meet the increasing demand for this resource due to restricted access to a fresh water supply. It is believed that countries with water resources below 2,000 m3 per capita per year may have difficulties meeting the needs of their population. In comparison, countries with resources below 1,000 m3 per capita per year are considered areas with a severe water deficit.

The structure of domestic water consumption shows that approximately 50% of drinking water can be replaced by rainwater; in public buildings, this value is almost 65% (Sly's, D. 2009).

Rooftop rainwater harvesting technologies are used worldwide to support consumption of water supply [5,6]; being the management of rainwater a way to mitigate the risk of flooding by reducing the volumes of water that reach the streets and storm drainage systems (Zhang, et al. 2010; Jones, M. and Hunt, W. 2010; Xing, Y. and Jones, P. 2019; Stec, et al. 2017).

These technologies also constitute one of the elements of more efficient operation in buildings, areas with dispersed housing, and the high costs of building classic water supply systems. They are an affordable and sustainable alternative to drinking water supply (Basinger, et al. 2010; Stec, A. and Zelenakova, M. 2019; Khan S. et al., 2017 and Kimani et al. 2015).

Once considered free and abundant, water resources are now becoming scarce, potentially affecting human well-being. Urban areas experience increased water demand directly proportional to the rate of urbanization, causing stress on water sources (Barthwal, et al. 2013).

Barthwal et al. (2013) also point out that collecting rainwater in cities and towns is an effective tool to recharge depleting aquifers and satisfy the water demand.

Water stress resulting from population growth, high water demand, and climate change currently represents a social and economic problem derived from the environment on a global, regional, and local scale (Morales-Figueroa, C. et al., 2023). The use of rainwater is a feasible option to reduce the scarcity of potable and non-potable water.

Ranaee, E. et al. (2021), points out that collecting rainwater through the roofs of houses for urban domestic activities can be a sustainable adaptation option with the growing demand for fresh water in urban areas.

Although very little is known about the benefits, rainwater harvesting offers users. Most studies have focused on theoretically estimating potential water catchment from rainwater harvesting (Ghisi et al. 2007; Sturm et al. 2009; Eroksuz and Rahman 2010).

Zhang et al. 2009; Rahman et al. 2010; Batchelor et al. 2011, indicate that the cost of rainwater harvesting is generally perceived as high, but economic analysis generally does not consider life cycle costs and various positive externalities.

The irregularity of the rains, the frequent droughts, and the absence of public policies oriented towards social development explain the need to implement rainwater collection systems to increase the water supply (Alves, H., and Farias, M. 2015).

Collecting rainwater and its subsequent storage in cisterns is one of the increasing alternatives to reduce the number of people without access to water for human consumption (UNEP. 2009).

Rainwater harvesting systems comprise at least: rain collection surfaces, a storage system, and gutters connecting the catchment area with storage (Wallace et al., 2015).

Depending on the needs and availability of resources in different countries, rainwater collection systems have different purposes. Developed countries mainly use rainwater for non-potable needs, such as irrigation, washing clothes, and flushing toilets (Villarreal, E. and Dixon, A. 2005).

Urbanization is a growing global trend, more than 50% of the world population currently lives in cities, and there are more than 500 cities that now have more than 1 million inhabitants (ONU, 2010). This growth, accompanied by the rapid increase in urban areas, dramatically impacts the hydrology and immediate availability of water (Buettner, 2015).

Jennings et al. (2010) detected the influence of cities on precipitation. For their part, Burian, S., Shepher, J. (2005), Krajewski et al. (2011), and Niyogi et al. (2011) detected the influence of urbanization on rainfall and climatology. Miao et al. (2011) and Shem and Shepherd (2009) confirm the observational evidence of the significant effect of urban land cover on rainfall variability.

Parkes et al. (2010) suggest that the water supplied by rainwater harvesting [RWH] systems generally requires higher operational energy to place in the networks. However, Ward et al. (2011) point out that this depends on the context and technological innovation in the design of RWH systems; They may have low or no power consumption. Jiang et al. (2013), found that RWH systems can lead to decreased energy use. Other projects use rainwater collected inside houses for thermal energy recovery and building cooling (An et al., 2015, Kollo, m. and Laanearu, J. 2015).

Incorporating demands that align with local rainfall patterns can substantially increase the efficiency of RWH systems in terms of water conservation and stormwater mitigation (Zhang et al., 2009).

In their research, Pochwat, et al. (2017) indicate that several countries worldwide have implemented rainwater collection and storage systems. Water collected in this way is a valuable source of fresh water that can reduce the demand for tap water and be used during periods of drought.

The water use systems result from each region's needs, available resources, rainfall, and environmental conditions. Only when there is no drinking water network, the supply is deficient, or the cost of water is very high do you think about looking for alternative supply systems." (Suárez, J. et al., 2006).

The factors of climate change, population increase, lack of control of illegal water intakes in rivers and channels, and agricultural and mining expansion are the main factors that cause different regions of Chile to find themselves with a notable scarcity of water resources. (Bull, N. 2022).

This work shows the results of an investigation carried out in different regions of Chile on implementing a catchment system for the use of rainwater on roofs of houses for the family benefit and as a palliative measure for the water crisis.

1.1. Goals

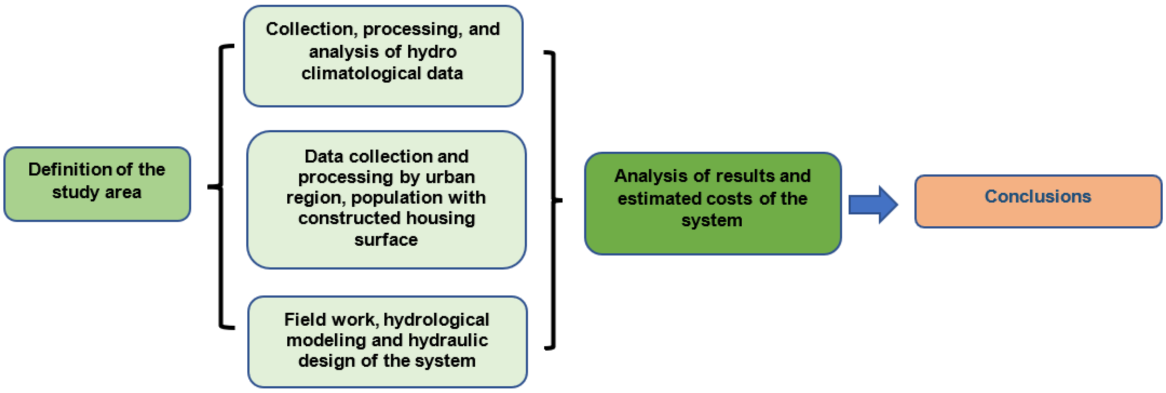
This work shows the results of the study of rainwater collection from the roofs of houses in the different regions of Chile; and how the implementation of collection systems can support the provision of drinking water to families as a palliative solution to the water crisis.

- An experimental phase of model houses is proposed to obtain an estimate of the volume of water collected based on the material of the roofs.
- Conduction and storage systems for water collected from the roofs are proposed.
- Establish a notion of contribution to family consumption of drinking water rain.
- Give an account of the beneficial impact of using rainwater for each region.
- Demonstrate the quantitative impact on the decrease in population consumption of regional and national drinking water for implementing a catchment system and use of rainwater.

2. Methodology

This section describes the methodology used for the hydrological simulation carried out in the study basin. Figure 1 outlines the development phases of the work.

Figure 1: Project development scheme



Definition of the study area

Collection, processing, and analysis of hydro climatological data

Data collection and processing by urban region, population with constructed housing surface

Field work, hydrological modeling and hydraulic design of the system

Analysis of results and estimated costs of the system

Conclusions

2.1. Study area

The work will be carried out with public data on the Chilean national territory's sectorization by region. The guidelines will also be provided for a base plane in the Mechanism for capturing rainwater from the house's roof. Figure 2 shows the location of the study area.

Figure 2: Location of the study area - Chile

2.2. Hydrological modeling and hydraulic design

The hydro climatological data were obtained from the pluviometric stations of the Chilean Meteorological Department for the macro-regions in order to obtain representative precipitation data for each of these regions.

For the evaluation and hydrological modeling, total annual rainfall will be used, in order to have a global volume of water that can be captured.

With the effect of locating the study and obtaining minimum parameters, a minimum rainfall regime was used as the predominant data and the maximum as the object of analysis.

For the hydraulic design, the roof coverings of the houses are considered as an initial part of the collection process, to then be conducted to the receiving channels and through the slope of these go by gravity to the rainwater downspout collector, where it is proposed to pass through a simple filter to have the final stage of storage in a cistern.

2.2.1. Field work

An experimental work was carried out in the field in order to have real data, for this, the collection of rainwater was carried out from the roofs of standard and traditional houses in Chile.

The field work carried out was carried out in 4 houses in the San Antonio commune, located on the southern coast of the Valparaíso region. The water coming from the roofs of known dimensions of three types (slate, asphalt tile and zinc) was captured and measured, which are the most used at the country level.

They were measured by rainfall event; the experience data was organized and probable volumes of water to be captured by supply surface were obtained.

2.2.2. Data collection and processing by urban population region with built-up housing surface

The research analyzes the different types of roofs traditionally used in the homes of the Chilean population, data that were obtained from the National Institute of Statistics of Chile (INE). The number of residential properties and their constructed area by 2021 were also analyzed.

The data is organized in a layout that reflects the most statistically representative housing area of each of the 16 regions of the country.

With these results, it is possible to demonstrate the global catchment surface by region and to be able to obtain a theoretical surface that is most adapted to its location and achieve the total volume to be captured from the roofs of family dwelling roofs.

2.3. Results and estimated budget

The results will allow visualizing the volumes of water collected from the roofs and that can be used immediately by families.

The unit costs of the proposed system will be estimated in order to be able to elaborate future catchment projects at the regional and family level.

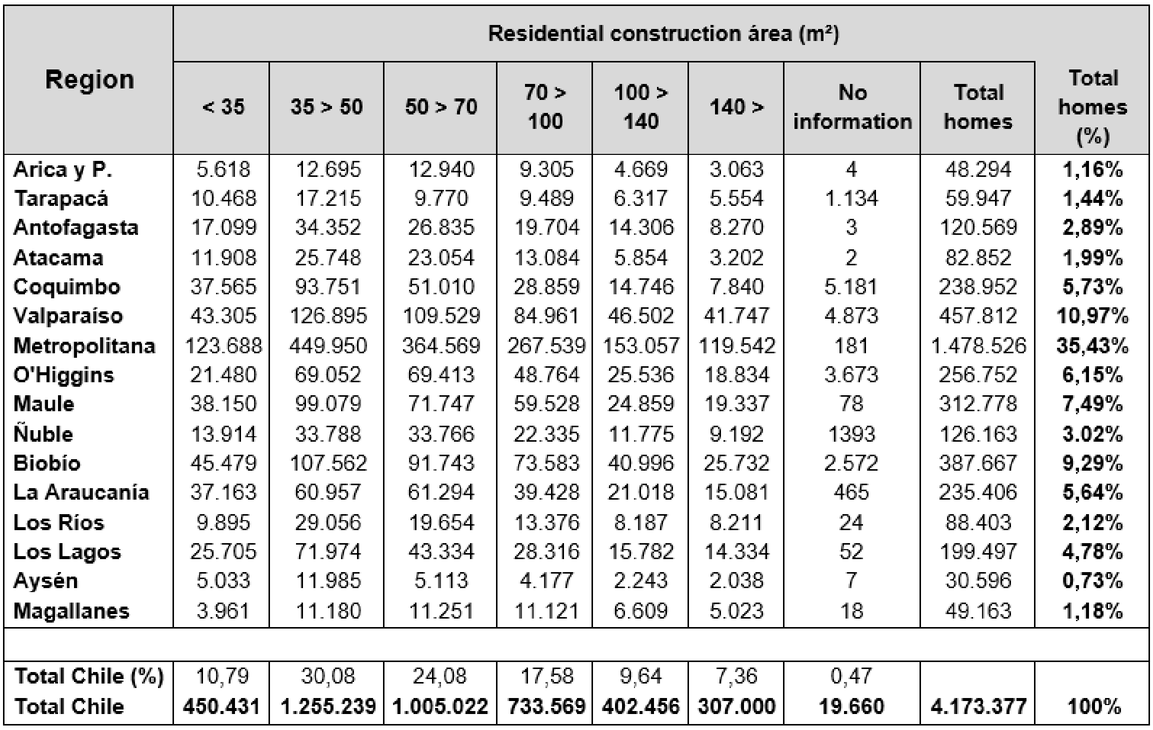
3. Results and discussion

The results of the investigation are detailed below.

3.1. Analysis of the constructed area – homes and Water demand estimation

The table 1 shows the detail of the housing surface built in Chile according to the information provided by the Chilean Internal Revenue Service (Servicio de Impuestos Internos [SII], 2023).

Table 1. Area of houses built in Chile



Region	**Residential construction área (m^2)**								**Total homes (%)**
	< 35	**35 > 50**	**50 > 70**	**70 > 100**	**100 > 140**	**140 >**	**No information**	**Total homes**	
Arica y P.	5.618	12.695	12.940	9.305	4.669	3.063	4	48.294	**1,16%**
Tarapacá	10.468	17.215	9.770	9.489	6.317	5.554	1.134	59.947	**1,44%**
Antofagasta	17.099	34.352	26.835	19.704	14.306	8.270	3	120.569	**2,89%**
Atacama	11.908	25.748	23.054	13.084	5.854	3.202	2	82.852	**1,99%**
Coquimbo	37.565	93.751	51.010	28.859	14.746	7.840	5.181	238.952	**5,73%**
Valparaíso	43.305	126.895	109.529	84.961	46.502	41.747	4.873	457.812	**10,97%**
Metropolitana	123.688	449.950	364.569	267.539	153.057	119.542	181	1.478.526	**35,43%**
O'Higgins	21.480	69.052	69.413	48.764	25.536	18.834	3.673	256.752	**6,15%**
Maule	38.150	99.079	71.747	59.528	24.859	19.337	78	312.778	**7,49%**
Ñuble	13.914	33.788	33.766	22.335	11.775	9.192	1393	126.163	**3.02%**
Biobío	45.479	107.562	91.743	73.583	40.996	25.732	2.572	387.667	**9,29%**
La Araucanía	37.163	60.957	61.294	39.428	21.018	15.081	465	235.406	**5,64%**
Los Ríos	9.895	29.056	19.654	13.376	8.187	8.211	24	88.403	**2,12%**
Los Lagos	25.705	71.974	43.334	28.316	15.782	14.334	52	199.497	**4,78%**
Aysén	5.033	11.985	5.113	4.177	2.243	2.038	7	30.596	**0,73%**
Magallanes	3.961	11.180	11.251	11.121	6.609	5.023	18	49.163	**1,18%**
Total Chile (%)	10,79	30,08	24,08	17,58	9,64	7,36	0,47		
Total Chile	**450.431**	**1.255.239**	**1.005.022**	**733.569**	**402.456**	**307.000**	**19.660**	**4.173.377**	**100%**

Source: Toro, N. 2022

The data shows that of the total housing built in Chile, 75.89% (4,173,377) corresponds to houses and 24.11% (1,326,010) to apartments. These data allow calculating and determining the approximate areas of roofs that are the rainwater collection factors. Table 2 shows the area of roofs using a standard surface.

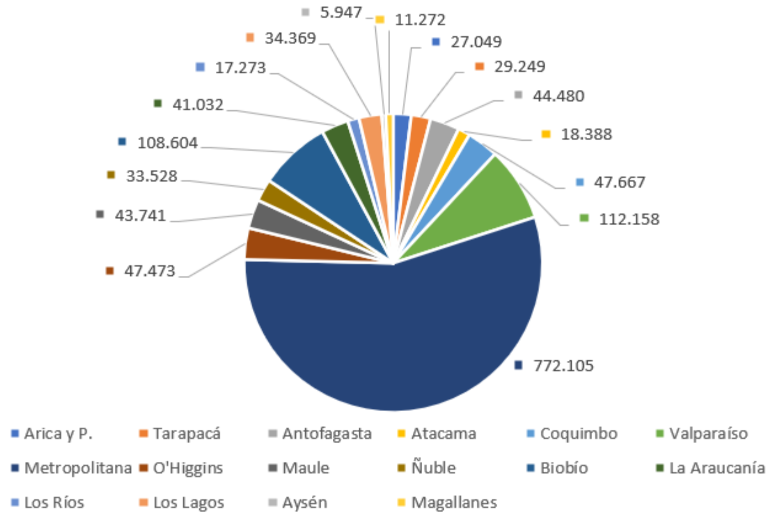
Table 2. Roof area

Region	City	N° homes	Roofs (m²)	Total roofs (m²)
Arica y P.	Arica	66.182	57,9	3.834.432
Tarapacá	Iquique	59.947	54,4	3.258.583
Antofagasta	Antofagasta	164.301	56,2	9.240.049
Atacama	Copiapó	53.535	55,3	2.960.559
Coquimbo	La Serena	160.514	51,3	8.226.395
Valparaíso	Valparaíso	145.590	57,7	8.400.160
Metropolitana	Gran Santiago	2.069.133	57,9	119.819.055
O'Higgins	Rancagua	87.856	57,8	5.080.302
Maule	Curicó	77.154	56,8	4.379.917
Ñuble	Chillán	61.246	57,2	3.504.651
Biobío	Concepción	83.641	57,0	4.771.557
La Araucanía	Temuco	97.534	56,2	5.484.448
Los Ríos	Valdivia	55.791	56,1	3.132.391
Los Lagos	Puerto Montt	136.075	54,7	7.445.543
Aysén	Coyhaique	18.896	53,1	1.003.337
Magallanes	Punta Arenas	46.306	60,7	2.808.971

Source: Toro, N. 2022

Figure 3 shows the distribution of demand in the regions of Chile. It is observed that the metropolitan area is the one with the most significant demand.

Figure 3: Water demand in Chile (Mm^3/year)



Source: Toro, N. 2022

3.2. Rainfall situation and analysis by zones

For a representative pluviometric measurement, the millimeters of water falling sectorally guided based on isohyets are analyzed. The volumes possible to capture by roof surface in the houses were calculated.

3.2.1. North and central zone

In the northern part of the country, considering the regions of Arica and Parinacota, Tarapacá, Antofagasta, Atacama, and Coquimbo, they have the lowest surface and underground water supply in the country.

Rainfall data indicates that Arica, Parinacota, and Tarapacá could generate an annual volume of up to 7.9 [Mm^3/year], contributing between 0.01 and 0.03% of the demand. While Antofagasta, Atacama, Coquimbo Parinacota, and Tarapacá could contribute between 0.11 and 1.36% of the demand.

The country's central zone, including the regions of Valparaíso, Metropolitana, O'Higgins, and Maule, has the lowest water supply in the coastal basins. Pluviometric data show that these areas can generate water volumes between 2,797.9 and 31,889.8 [Mm^3/year] of Greater Santiago, contributing to water demand between 3 and 7%.

3.2.2. South and southern zone

The southern zone includes the regions of Ñuble, Biobío, La Araucanía, Los Ríos, and Los Lagos. These areas have the highest offers in the basins of the main and largest rivers in these regions, mostly shared between regions. Hydrological data show that these areas can generate water volumes between 2,713.2 and 11,484.7 [Mm^3/year] with the project, contributing to approximately 8% and 33% demand.

The southern zone of the national territory considers the last two regions of Aysén and Magallanes. In these, the coastal basins and canals stand out as a source, possessing almost all of the water supply due to a large amount of their flow. With the implementation of the project, volumes of water can be generated that are between 1,013.1 and 1,099.8 [Mm^3/year], which means contributions to demand between 9% and 17%.

3.3. Analysis of economic and social feasibility

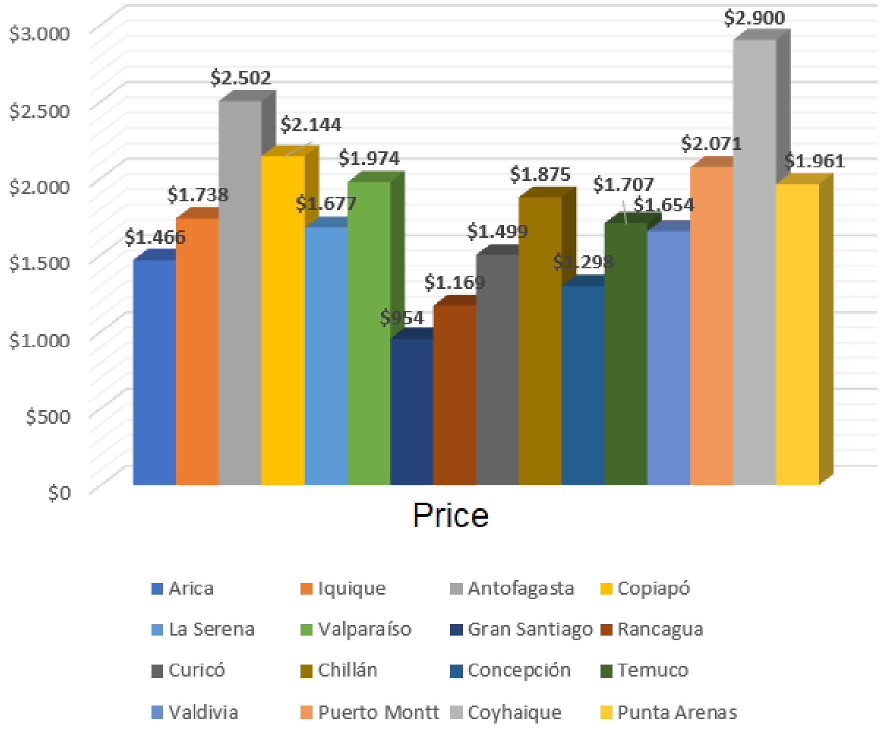
Water costs vary depending on the region, city, and operating company. Figure 4 shows this variation, with Antofagasta and Coyhaique having the highest cost.

Table 3 shows the projection of savings for each square meter of roof surface, obtaining the savings per year that can be achieved using rainwater collected from the roofs and estimated in the project.

The table shows that the cities shaded in orange, where Arica, Iquique, Antofagasta, Copiapó, and La Serena are located, have the lowest projected cost savings from the drinking water network. This is due to the low rainfall in the areas.

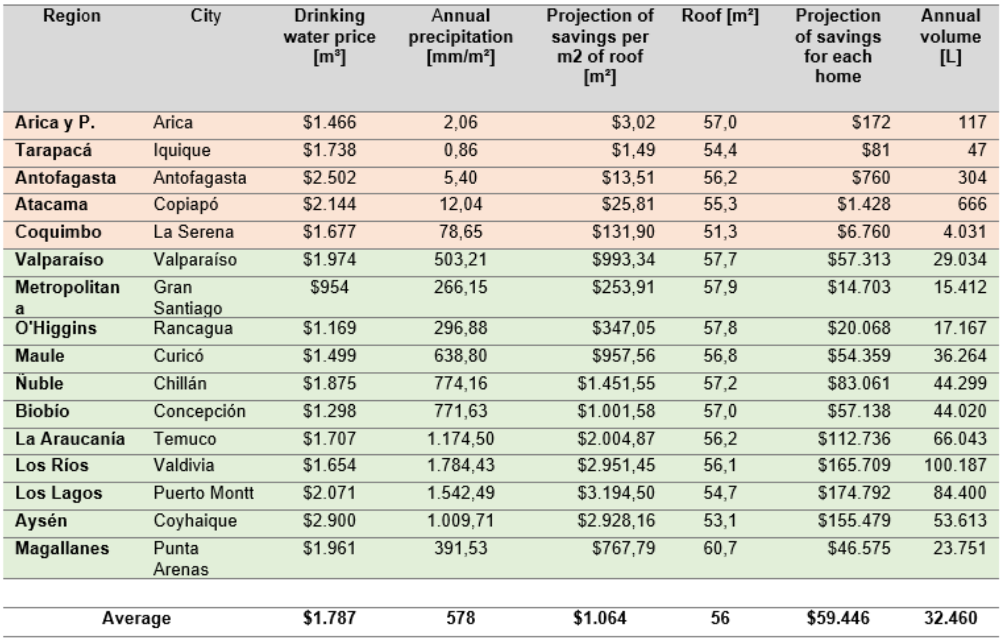
On the other hand, the cities in green, corresponding to Valparaíso, Gran Santiago, Rancagua, Curicó, Chillán, Concepción, Temuco, Valdivia, Puerto Montt, Coyhaique, and Punta Arenas, show a better projection of savings due to having better rainfall conditions than achieving better annual volumes of water. In terms of usage, they can cover weeks and even months of water consumption.

Figure 4: Price per cubic meter of water by city



The savings amounts range from $14,000 for Greater Santiago to $174,000 for Puerto Montt.

Table 3. Savings obtained with the implementation of the project

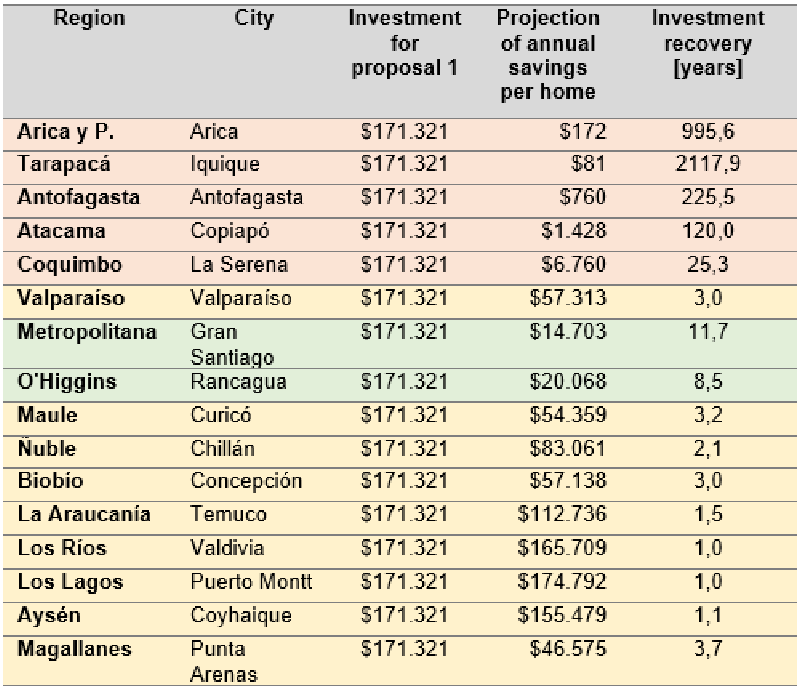


Region	City	Drinking water price [m^3]	Annual precipitation [mm/m^2]	Projection of savings per m2 of roof [m^2]	Roof [m^2]	Projection of savings for each home	Annual volume [L]
Arica y P.	Arica	$1.466	2,06	$3,02	57,0	$172	117
Tarapacá	Iquique	$1.738	0,86	$1,49	54,4	$81	47
Antofagasta	Antofagasta	$2.502	5,40	$13,51	56,2	$760	304
Atacama	Copiapó	$2.144	12,04	$25,81	55,3	$1.428	666
Coquimbo	La Serena	$1.677	78,65	$131,90	51,3	$6.760	4.031
Valparaíso	Valparaíso	$1.974	503,21	$993,34	57,7	$57.313	29.034
Metropolitana	Gran Santiago	$954	266,15	$253,91	57,9	$14.703	15.412
O'Higgins	Rancagua	$1.169	296,88	$347,05	57,8	$20.068	17.167
Maule	Curicó	$1.499	638,80	$957,56	56,8	$54.359	36.264
Ñuble	Chillán	$1.875	774,16	$1.451,55	57,2	$83.061	44.299
Biobío	Concepción	$1.298	771,63	$1.001,58	57,0	$57.138	44.020
La Araucanía	Temuco	$1.707	1.174,50	$2.004,87	56,2	$112.736	66.043
Los Ríos	Valdivia	$1.654	1.784,43	$2.951,45	56,1	$165.709	100.187
Los Lagos	Puerto Montt	$2.071	1.542,49	$3.194,50	54,7	$174.792	84.400
Aysén	Coyhaique	$2.900	1.009,71	$2.928,16	53,1	$155.479	53.613
Magallanes	Punta Arenas	$1.961	391,53	$767,79	60,7	$46.575	23.751
Average		**$1.787**	**578**	**$1.064**	**56**	**$59.446**	**32.460**

Two rainwater harvesting systems collected from roofs are proposed. A system that includes collecting water through PVC gutters and storage through plastic tanks of 1000 l. Another system that considers only the placement of the storage tank.

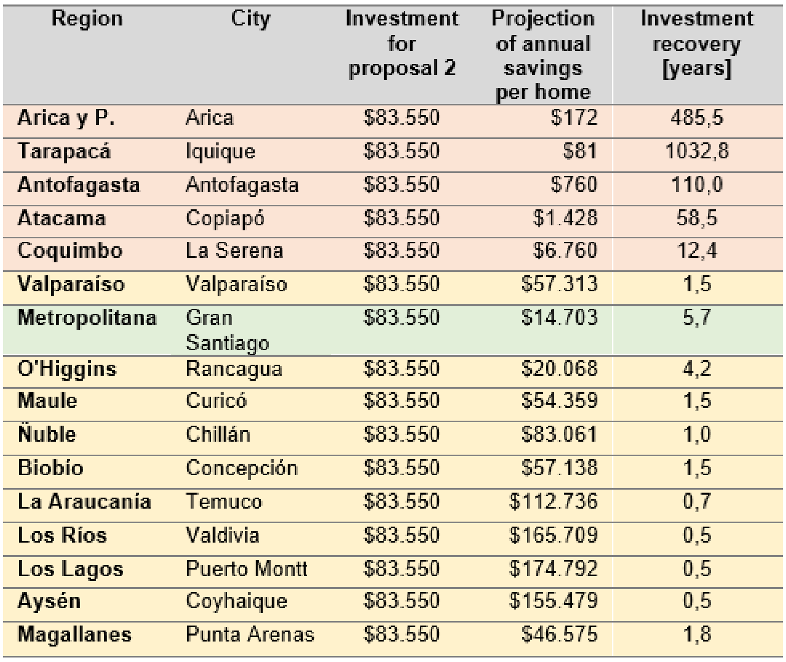
For the first system, an investment cost of $171,321 is estimated, and for the second of $83,550, the investment recovery projection is shown in Tables 4 and 5.

Table 4. Recovery Projection for System 1



Region	City	Investment for proposal 1	Projection of annual savings per home	Investment recovery [years]
Arica y P.	Arica	$171.321	$172	995,6
Tarapacá	Iquique	$171.321	$81	2117,9
Antofagasta	Antofagasta	$171.321	$760	225,5
Atacama	Copiapó	$171.321	$1.428	120,0
Coquimbo	La Serena	$171.321	$6.760	25,3
Valparaíso	Valparaíso	$171.321	$57.313	3,0
Metropolitana	Gran Santiago	$171.321	$14.703	11,7
O'Higgins	Rancagua	$171.321	$20.068	8,5
Maule	Curicó	$171.321	$54.359	3,2
Ñuble	Chillán	$171.321	$83.061	2,1
Biobío	Concepción	$171.321	$57.138	3,0
La Araucanía	Temuco	$171.321	$112.736	1,5
Los Ríos	Valdivia	$171.321	$165.709	1,0
Los Lagos	Puerto Montt	$171.321	$174.792	1,0
Aysén	Coyhaique	$171.321	$155.479	1,1
Magallanes	Punta Arenas	$171.321	$46.575	3,7

Table 5. Recovery Projection for System 2



Region	City	Investment for proposal 2	Projection of annual savings per home	Investment recovery [years]
Arica y P.	Arica	$83.550	$172	485,5
Tarapacá	Iquique	$83.550	$81	1032,8
Antofagasta	Antofagasta	$83.550	$760	110,0
Atacama	Copiapó	$83.550	$1.428	58,5
Coquimbo	La Serena	$83.550	$6.760	12,4
Valparaíso	Valparaíso	$83.550	$57.313	1,5
Metropolitana	Gran Santiago	$83.550	$14.703	5,7
O'Higgins	Rancagua	$83.550	$20.068	4,2
Maule	Curicó	$83.550	$54.359	1,5
Ñuble	Chillán	$83.550	$83.061	1,0
Biobío	Concepción	$83.550	$57.138	1,5
La Araucanía	Temuco	$83.550	$112.736	0,7
Los Ríos	Valdivia	$83.550	$165.709	0,5
Los Lagos	Puerto Montt	$83.550	$174.792	0,5
Aysén	Coyhaique	$83.550	$155.479	0,5
Magallanes	Punta Arenas	$83.550	$46.575	1,8

The tables highlight 3 ranges of time to recover the investment; the cities shaded in orange whose recovery time is greater than 12 years. The cities in green with recovery times that are between 5 and 8 years, and the cities in yellow with times of less than 5 years.

3.4. Experimental fieldwork and normal water collection

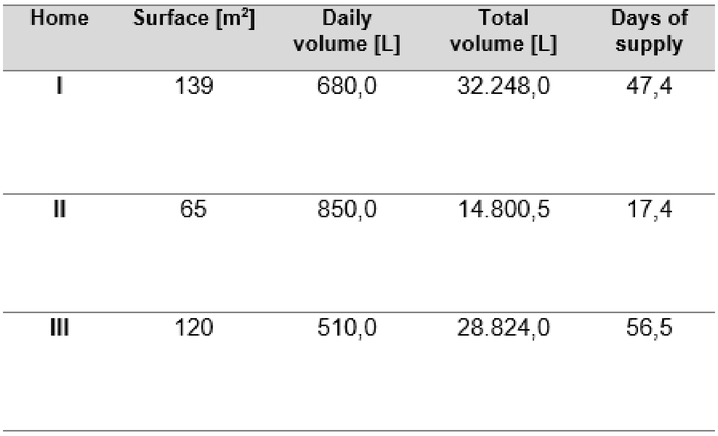
The experimental work allowed obtaining fundamental parameters and distinctions for the simulations and subsequent calculations. In the first place, it was possible to categorize and classify the size of the houses and the collection areas of the roofs. Rainwater collections were made from the roofs of model homes, and the volumes of water collected were quantified. These data have served as comparative and validation parameters.

The measurements of water collected from the roofs were carried out from April until the end of September. Table 6 shows the total volume accumulated on the collection days and the daily volume that could be had.

The experimental work was carried out in 3 model houses. The results show that the type 1 dwelling with a roof area of 139 m2 can capture up to 680 L/day, which can supply up to 47 days. The type II house collects up to 850 L/day and can supply up to 17 days, while the type III house supplies up to 56 days. It is essential to point out that the dwellings analyzed correspond to family units of 4, 5, and 3 inhabitants, respectively.

The rain data together with the protection of the surface of a roof provide a defined volume of water to be captured, applied to each one of the regions of the country.

Table 6. The volume of water collected during fieldwork



Home	Surface [m²]	Daily volume [L]	Total volume [L]	Days of supply
I	139	680,0	32.248,0	47,4
II	65	850,0	14.800,5	17,4
III	120	510,0	28.824,0	56,5

Rainwater collection applied to family units is defined as a system that captures water from roofs, conducts it through gutters and downspouts, and stores it in tanks. Figure 5 shows the scheme of how the rainwater harvesting process looks through the roofs and figure 6 shows the experimental process carried out in the investigation.

Figure 5: Diagram of the rainwater collection system through the roofs

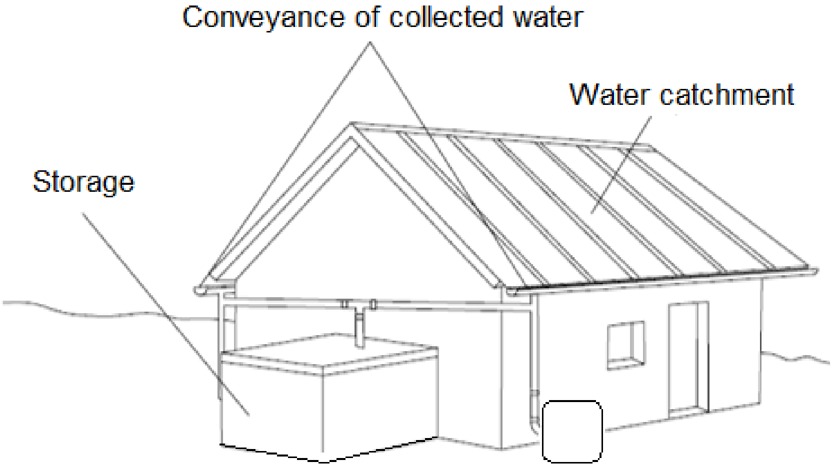


Figure 6: Water collection in experimental work

4. Conclusions

The rainfall study of the main regions of Chile shows a capacity to contribute as a form of benefit to a new unconventional water source, which can be seen as a palliative measure for the water scarcity that the country is experiencing and as a secondary source that could stay in residential buildings. The hydrological analysis shows the variations in rainfall between regions; while the North and Center regions show low rainfall, the South and Austral regions have better rainfall behavior.

The project's impact on the national water demand projected until 2030 shows that the use of rainwater and its incorporation into the water supply system in the 16 cities generates a reduction of the water deficit by 5.25%, which means some 73,190 million cubic meters of water. These results show that the project generates a positive impact every time the direct benefits reach the neediest properties.

The cost of implementing a collection system for a 120 m2 type surface, which considers improvement of the roof, 16 m long channels and a 1,000 L tank for $171,328 (200 euros).

The experimental work carried out in the model houses shows the ease with which water can be captured and stored during rainy episodes. The rainwater collection system for homes captures water through the roof, conducts it through gutters and downspouts, and stores it in tanks.

The analysis of socioeconomic profitability indicates that in the regions of Coquimbo, Valparaíso, Metropolitana, O'Higgins, Maule, Ñuble, Biobío, La Araucanía, Los Ríos, Los Lagos, Aysén, and Magallanes, it is advisable to incorporate a system catchment for rainwater storage, since it can generate an economic benefit due to savings in water consumption, in the medium and short term this last point increases as the location is further south of the Chilean territory.

With the application of the catchment system, the northern zone will be able to catch between 3 and 647 Mm^3/year, which means a decrease in the regional demand for potable water of up to 1.4%. The central zone can capture between 4,300 and 32,000 Mm^3/year, with a decrease in water demand of up to 6.5%, while the southern zone reaches a decrease in demand of up to 15% with catchments of 2,700 to 6,700 Mm^3/year.

References

Alves, H. & Farias, M. (2015). Potential for Rainwater Catchment's as an Alternative for Human Consumption in Drier Micro-Region of the State of Paraiba, Brazil. International Journal of Research in Geography. 1(2), 32-37. Obtained on 03-29/2023 from: https://www.researchgate.net/profile/Hermes-Almeida/publication/299533017_Potential_for_Rainwater_Catchment's_as_an_Alternative_for_Human_Consumption_in_Drier_Micro-Region_of_the_State_of_Paraiba_Brazil_Maysa_Porto_FARIAS/links/56fd67e708ae1408e15b2e7a/Potential-for-Rainwater-Catchments-as-an-Alternative-for-Human-Consumption-in-Drier-Micro-Region-of-the-State-of-Paraiba-Brazil-Maysa-Porto-FARIAS.pdf

An, K., Lam, Y., Hao, S., Morakinyo, T. & Furumai, H. (2015). Multi-purpose rainwater harvesting for water resource recovery and the cooling effect. Water Res. 86, 116-121. http://dx.doi.org/10.1016/j.watres.2015.07.040.

Batchelor, C., Fonseca, C. & Smits, S. (2011). Life-cycle Costs of Rainwater Harvesting Systems. (Occasional Paper 46). IRC International Water and Sanitation Centre, WASHCost and RAIN. The Hague, The Netherlands.

Barthwal, S., Chandola-Barthwal, S., Goyal, H., Nirmani, B. & Bhawana Awasthi. (2012). Socio-economic acceptance of rooftop rainwater harvesting – A case study. Urban Water Journal. 231-239. https://doi.org/10.1080/1573062X.2013.765489.

Basinger, M., Montalto, F. & Lall, U. (2010). A rainwater harvesting system reliability model based on nonparametric stochastic rainfall generator. J. Hydrol. 392, 105–118. https://doi.org/10.1016/j.jhydrol.2010.07.039.

Buettner, T. (2015). Urban Estimates and Projections at the United Nations: The Strengths, Weaknesses, and Underpinnings of the World Urbanization Prospects. *Spat Demogr*. 3, 91-108. Obtained from DOI 10.1007/s40980-015-0004-2

Burian, S., & Shepherd, J. (2005). Effect of urbanization on the diurnal rainfall pattern in Houston. *Hydrol Process*. 19, 1089–1103. Obtained from DOI: 10.1002/hyp.5647

Christensen, J.H., Carter, T.R., Rummukainen, M. & Amanatidis, G. (2007). Evaluating the performance and utility of regional climate models: The PRUDENCE project. *Clim. Chang.* 81, 1–6. https://doi.org/10.1007/s10584-006-9211-6

Eroksuz, E. & Rahman, A. (2010) Rainwater Tanks in Multi-Unit Buildings: A Case Study for Three Australian Cities. Resour. Conserv. Recy., 54 (12), 1449–1452. https://doi.org/10.1016/j.resconrec.2010.06.010

Ghisi, E., Bressam, D.L. & Martini, M. (2007). Rainwater Tank Capacity and Potential for Potable Water Savings by Using Rainwater in the Residential Sector of Southeastern Brazil. Build. Environ. 42, 1654–1666. https://doi.org/10.1016/j.buildenv.2006.02.007

Jennings, SA., Lambert, MF., & Kuczera, G. (2010). Generating synthetic high resolution rainfall time series at sites with only daily rainfall using a master-target scaling approach. *J Hydrol*. 393, 163–73.

Jiang, Z., Li, X. & Ma, Y. (2013). Water and energy conservation of rainwater harvesting system in the loess plateau of China. J. Integr. Agric. 12 (8), 1389-1395. doi:10.1016/S2095-3119(13)60553-5.

Jones, M.P. & Hunt, W.F. (2010). Performance of rainwater harvesting systems in the southeastern United States. Resour. Conserv. Recycl. 54, 623–629. https://doi.org/10.1016/j.resconrec.2009.11.002.

Khan, S.T., Baksh, A.A., Papon, M.T.I. & Ali, M.A. (2017). Rainwater harvesting system: An approach for optimum tank size design and assessment efficiency. Int. J. Environ. Sci. Technol. 8, 37–43. doi: 10.18178/ijesd.2017.8.1.917

Krajewski, W., Kruger, A., Lawrence, L., Smith, J., Allen, A., Steiner, M., Baeck, M., Ramamurthy, M., Weber, J., DelGreco, S., Seo, B., Domaszczynski, P., Gunyon, C. & Goska, R. (2011). Towards better utilization of NEXRAD data in hydrology: an overview of hydro-NEXRAD. *J Hydroinform*. 13, 255–66.

Kimani, M.W., Gitau, N.A. & Ndunge, D. (2015). Rainwater Harvesting Technologies in Makueni County, Kenya. *Int. J. Eng. Sci.* 5, 39–49.

Kisakye, V. & Van der Bruggen, B. (2018). Effects of climate change on water savings and water security from rainwater harvesting systems. *Resources, Conservation and Recycling.* 138, 49-63. https://doi.org/10.1016/j.resconrec.2018.07.009.

Kollo, M. & Laanearu, J. (2015). An optimal solution of thermal energy usage in the integrated system of stormwater collection and domestic-water heating. Urban Water J. 212-222. DOI: 10.1080/1573062X.2015.1086006.

Mekonnen, M.M. & Hoekstra, A.Y. (2016). Four billion people facing severe water scarcity. Sci. Adv. 2, e1500323. Obtained from DOI: 10.1126/sciadv.1500323

Miao, S., Chen, F., Li, O. & Fan, S. (2011). Impacts of urban processes and urbanization on summer precipitation: a case study of heavy rainfall in Beijing on 1 August 2006. *J Appl Meteorol Climatol*. 50, 806–26. Obtained from DOI: 10.1175/2010JAMC2513.1

Morales-Figueroa, C., Castillo-Suárez, L.A., Linares-Hernández, I., Martínez-Miranda, V. and Teutli-Sequeira, E. (2023). Treatment processes and analysis of rainwater quality for human use and consumption regulations, treatment systems and quality of rainwater. Int. J. Environ. Sci. Technol. https://doi.org/10.1007/s13762-023-04802-2

Niyogi, D., Pyle, P., Lei, M., Arya, S., Kistawal, C. Shepherd, M & Chen, F. (2011). Urban Modification of Thunderstorms: An Observational Storm Climatology and Model Case Study for the Indianapolis Urban Region. *American Meteorological Society*. 50, 1129-1144. Obtained from DOI: 10.1175/2010JAMC1836.1

Organización de las Naciones Unidas [ONU], (2010). Perspectivas de urbanización mundial: la revisión de 2009 Departamento de Asuntos Económicos y Sociales de las Naciones Unidas (División de Población). Nueva York.

Orlińska-Woźniak, P., Wilk, P. & Gębala, J. (2013). Water availability in reference to water needs in Poland. *Meteorol. Hydrol. Water Manag*. 1, 45–50. Obtained from: file:///C:/Users/USUARIO/Downloads/orlinska-wozniak_wilk_gebala_water_1_2013.pdf

Parkes, C., Kershaw, H., Hart, J., Sibille, R. & Grant, Z. (2010). Energy and Carbon Implications of Rainwater Harvesting & Greywater Recycling. *Environment Agency, Bristol*. Final Report, Science Project Number: SC090018. http://publications.environment-agency.gov.uk/pdf/SCHO0610BSMQ-e-e.pdf

Pochwat, K., Sły´s, D. & Kordana, S. (2017). The temporal variability of a rainfall synthetic hyetograph for the dimensioning of storm-water retention tanks in small urban catchments. J. Hydrol. 549, 501–511. https://doi.org/10.1016/j.jhydrol.2017.04.026

Rahman, A., Dbais, J. & Imteaz, M. (2010). Sustainability of Rainwater Harvesting Systems in Multistorey Residential Buildings. Am. J. Eng. Appl. Sci. 3 (1), 889–898. https://doi.org/doi:10.3844/ajeassp.2010.73.82

Ranaee, E., Abbasi, A., Yazdi, J., & Ziyaee, M. (2021). Feasibility of Rainwater Harvesting and Consumption in a Middle Eastern Semiarid Urban Area. Water. 13 (15), 2130. Obtained from https://doi.org/10.3390/w13152130

Shem, W., & Shepherd, M. (2009). On the impact of urbanization on summertime thunderstorms in Atlanta: two numerical model case studies. *Atmos Res*. 92, 172–89. Obtained from doi:10.1016/j.atmosres.2008.09.013.

Servicio de Impuestos Internos [SII]. Chile. Obtained from: https://homer.sii.cl/

Suarez, J., García, M. & Mosquera, R. (2006). HISTORIA DE LOS SISTEMAS DE APROVECHAMIENTO DE AGUA LLUVIA. VI SEREA - Seminário Iberoamericano sobre Sistemas de Abastecimento Urbano de Água João Pessoa (Brasil), 5 a 7 de junho de 2006. Obtained from: https://sswm.info/sites/default/files/reference_attachments/BALLEN%20et%20al.%202006.%20Historia%20de%20los%20sist%20de%20aprovechamiento%20agua%20lluvia.pdf.

Sly´s, D. (2009). Potential of rainwater utilization in residential housing in Poland. Water Environ. J. 23, 318–325. https://doi.org/10.1111/j.1747-6593.2008.00159.x

Stec, A., Kordana, S. & Slys, D. (2017). Analysing the financial efficiency of use of water and energy saving systems in single-family homes. J. Clean Prod. 151, 193–205. https://doi.org/10.1016/j.jclepro.2017.03.071.

Stec, A. & Zelenakova, M. (2019). An Analysis of the effectiveness of two rainwater harvesting systems located in central eastern Europe. Water. 11, 458. https://doi.org/10.3390/w11030458.

Sturm, M., Zimmermann, M., Schütz, K., Urban, W. & Hartung, H. (2009). Rainwater Harvesting As An Alternative Water Resource in Rural Sites in Central Northern Namibia. Phys. Chem. Earth. 34, 776–785. https://doi.org/10.1016/j.pce.2009.07.004.

Toro, N. (2022). Aprovechamiento de agua de lluvia captada a través de cubiertas de techumbres de zonas urbanas en todas las regiones de Chile para uso doméstico como una solución familiar y de aporte a la reducción de la demanda hídrica nacional. Tesis de grado (no publicada). Universidad Católica Boliviana, Bolivia y Pontificia Universidad Católica de Valparaiso, Chile.

United Nations Environment Programmer (UNEP) 2009. Rainwater harvesting: a lifeline for human well-being. *A report prepared for UNEP by Stockholm Environment Institute*. 69 p.

Villarreal, E & Dixon, A. (2005). Analysis of a rainwater collection system for domestic water supply in Ringdansen, Norrköping, Sweden. *Building and Environment*. 40 (9), 1174-1184. https://doi.org/10.1016/j.buildenv.2004.10.018.

Wang, X., Zhang, J., Gao, J., Shahid, S.; Xia, X., Geng, Z. & Tang, L. (2018). The new concept of water resources management in China: Ensuring water security in changing environment. Environ. Dev. Sustain. 20, 897–909. https://doi.org/10.1007/s10668-017-9918-8

Wallace, C., Bailey, T. & Arabi, M. (2015).Rainwater catchment system design using simulated future climate data. *Journal of Hydrology*.529(3), 1798-1809. https://doi.org/10.1016/j.jhydrol.2015.08.006.

Ward, S., Butler, D. & Memon, F. (2011). Benchmarking energy consumption and CO2 emissions from rainwater harvesting systems: an improved method by proxy. *Water Environ. J.* 26 (2), 184-190. DOI: 10.1111/j.1747-6593.2011.00279.x

Xing, Y. & Jones, P. (2019). In-situ monitoring of energetic and hydrological performance of a semi-intensive green roof and a white roof during a heatwave event in the UK. Indoor Built Environ. https://doi.org/10.1177/1420326X1988721.

Zdeb, M., Zamorska, J., Papciak, D. & Słyś, D. 2020. The Quality of Rainwater Collected from Roofs and the Possibility of Its Economic Use. *Resources*. *9*, 12. https://doi.org/10.3390/resources9020012.

Zhang, Y., Chen, D., Chen, L. & Ashbolt, S. (2009). Potential for Rainwater Use in High-Rise Buildings in Australian Cities. J. Environ. Manage. 91, 222–226. https://doi.org/10.1016/j.jenvman.2009.08.008.

Zhang, Y., Grant, A., Sharma, A., Chen, D. & Chen, L. (2010). Alternative Water Resources for Rural 5 Residental Development In Western Austarlia. Water Resour. Manag.24, 25–36. https://doi.org/10.1007/s11269-009-9435-0

Communication aligned with the Sustainable Development Goals

6 AGUA LIMPIA Y SANEAMIENTO

11 SUSTAINABLE CITIES AND COMMUNITIES