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IMPLEMENTATION OF A PILOT SYSTEM FOR HARVESTING FOG WATER FOR A SINGLE FAMILY SOLUTION IN THE "RINCON DE LA VITTORIA"

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The constant contamination of natural resources and the effect of climate change are the factors that generate water deficits in many countries of the world. In Tarija, Bolivia, the provision of water for human consumption is increasingly critical due to the contamination of various water sources. The use and application of cheap and easy-to-operate technologies and mechanisms are a solution that allows the generation of more significant volumes of water to reduce the water deficit; the harvesting of water from the mist is one of these technologies that makes it possible to improve the supply of water in dispersed family nuclei and rural areas.

This work shows the results achieved in an experimental pilot process for implementing water harvesting from dew and fog in the Rincón de la Vittoria area of the Department of Tarija, Bolivia. The prototype, which consists of a 1.5 m2 frame with a plastic mesh placed at the height of 2.5 m from the ground, shows that it can capture up to 15% of the average daily supply required by Bolivian Regulations for the design of drinking water systems, being a viable alternative to reduce the water deficit.

Keywords: water deficit; harvesting of water; water fog

IMPLEMENTACIÓN DE UN SISTEMA PILOTO DE COSECHA DE AGUA DE NIEBLA PARA SOLUCION UNIFAMILIAR EN EL "RINCON DE LA VITTORIA"

La constante contaminación de los recursos naturales y el efecto del cambio climático son los factores que generan déficit hídrico en muchos países del Mundo. En Tarija, Bolivia, la dotación de agua de consumo humano cada vez es más crítica debido a la contaminación de varias fuentes de agua. La utilización y aplicación de tecnologías y mecanismos económicos y fáciles de operar son una solución que permite la generación de mayores volúmenes de agua para disminuir el déficit hídrico, la cosecha de agua proveniente de la neblina es una de estas tecnologías que posibilita mejorar la dotación de agua en núcleos familiares dispersos y en zonas rurales. Este trabajo muestra los resultados logrados en un proceso experimental piloto de implementación de cosecha de agua proveniente del rocío y niebla en la zona del Rincón de la Vittoria del Departamento de Tarija, Bolivia. El prototipo que consiste en un marco de 1.5 m2 con una malla plástica colocada a una altura de 2.5 m del suelo, muestra que puede captar hasta el 15% de la dotación media diaria requerida por la Normativa Bolivia para el diseño de sistemas de agua potable, siendo una alternativa viable para disminuir el déficit de agua.

Palabras clave: déficit hídrico; cosecha de agua; neblina

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1. Introduction

Sustainable Development Goal (SDG) 6, which calls for access to safe drinking water and sanitation for all by 2030, supports efforts in water-scarce countries and regions to go beyond conventional resources and tap into unconventional water to reduce the gap between water supply and demand (Qadir, M. et al. 2018).

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 points out that collecting rainwater in cities and towns is an effective tool to recharge depleting aquifers and satisfy the water demand.

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).

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 rainwater harvesting for urban domestic activities can be a sustainable adaptation option with the growing demand for fresh water in urban areas.

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.

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).

Fletcher et al. 2013, find that urban hydrology has evolved to improve how water availability, urban runoff for flood protection, public health, and environmental protection are managed.

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.

Regarding the influence of urban areas on the flow, Dotto et al. (2011), Smith et al. (2005), Villarini et al. (2009), and Hawley and Bledsoe (2011) confirm that urbanization and the nature and layout of the drainage network play a dominant role in the hydrology of the basin. The influence of urban areas on the peaks and duration of flows has a significant effect, especially in times of higher precipitation.

While the practice of alternative water harvesting, such as rainwater (RHW) or mist, dates back millennia, its modern implementation varies greatly; often with systems that do not maximize potential benefits. Economic restrictions and local regulations strongly influence the degree of implementation of these systems and the selection of technology (Campisano, et al. 2017).

Furthermore, Campisano et al. (2017) point out that even though design protocols have been established in many countries, the recommendations are often organized only to conserve water without considering other potential benefits.

Campisano et al. (2017), suggest that future work on these water collection systems addresses three priority challenges. First, more empirical data on system performance is needed for better modeling considering multiple system objectives. Second, maintenance aspects and how they can affect the quality of collected water need to be explored in the future to increase confidence in the use of collected water. Ultimately, research should be devoted to understanding how institutional and sociopolitical support can best be targeted to improve system effectiveness and community acceptance.

Parkes et al. (2010) suggest that water supplied by alternative systems such as rain (RWH) or mist generally requires higher operating energy to enter the networks. However, Ward et al. (2011) points out that this depends on the context and technological innovation in the design of the systems; They may have low or no power consumption. Jiang et al. (2013) found that the systems can lead to a decrease in 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).

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

Fog is a potential source of water that could be exploited using innovative fog harvesting technology. Demonstrating that fog has great importance in cloud forests that thrive thanks to the interception of fog (Fessehaye, et al., 2014).

Fessehaye, et al., 2014, also points out that a fog water harvesting technology is simple, cost-effective, and energy free. However, fog water harvesting has the disadvantages that it is seasonal and localized, and the technology needs continuous maintenance.

Several countries could ensure the sustainability of fog water harvesting technology if technical, economic, social, and managerial factors are addressed during its planning and implementation (Fessehaye, et al., 2014).

Rivera, O. (2017) points out that a fog water collection system from implemented collectors can reach 1.33 liters of water per day for the fog gauge and 9.83 liters of fog water.

As the scarcity of clean water becomes a severe problem for humanity, collecting atmospheric water has become a viable solution (Nioras, D. 2021).

There are two main approaches to collecting water from the atmosphere: the first is to capture it from fog, while the second is through vapor condensation on surfaces with a temperature below the dew point. The water collection mechanism in these two modes is entirely different (Nioras, D. 2021).

Clus, O. et al., 2012, in his research, he demonstrates that the application of dew water collection devices through pilot condensers with a total surface area of 136 m2 is not only effective in dew water condensation but also collects rain and fog, thus providing the population with valuable water resource.

Lekouch I. et al. (2011) show that dew and fog water collection systems can capture essential water for supply. Four passive dew condensers and one passive mist net collector were used, each with surfaces of 1 m2. A cost analysis shows that, with little investment, spray water can be turned into a valuable complementary alternative water resource.

Fog water harvesting is a passive, low-maintenance, and sustainable option to supply fresh drinking water to communities where fog events are expected. Due to the relatively simple design of mist collection systems, their operation and maintenance are minimal, as is the associated cost (Qadir, M. et al. 2018).

The Municipality of Tarija, located in the Department of Tarija, Bolivia, represents the largest population in the department, generating the most important environmental and water impacts, especially the drinking water supply (Copa and Villena, 2016).

The community of "El Rincón de la Victoria" is a town in the Municipality of Tarija and currently has severe problems with the supply of water for consumption, having one of the highest population growth rates in the department (Baldivieso, L. 2021).

This work shows the results of a pilot test developed with the implementation of a prototype fog water collection system in the town of Rincón de la Vittoria and how the volumes of water collected to contribute to solving the problem of water scarcity in other localities with similar situations. It is proposed as a case of future application to the town of Cirminuelas, which presents a vulnerability to water and climatic conditions similar to the study area.

1.1. Goals

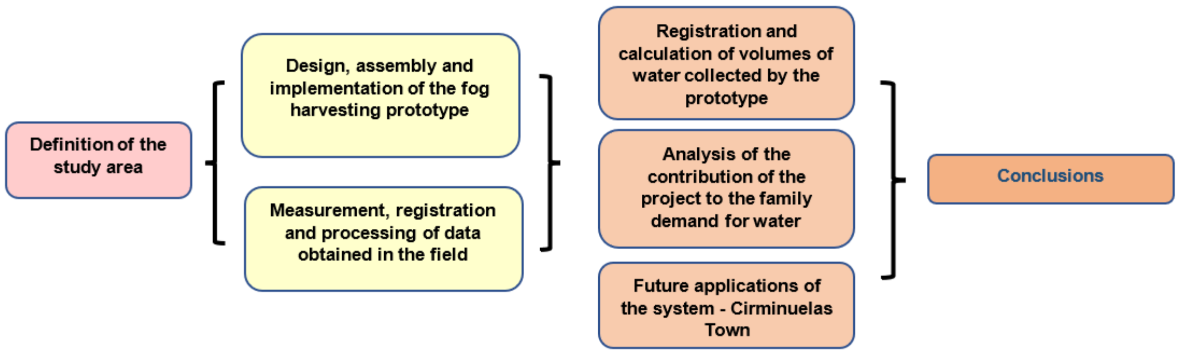
This work aims to show the results achieved in the pilot test carried out with the implementation of a prototype for the collection of fog water installed in the town of Rincón de la Vittoria as an alternative proposal at a single-family level to generate a water supply.

- The design and implementation of a fog water collection prototype are presented.
- Collect data daily for a specified time.
- Determine the efficiency of the collection system.
- Assess the amount of water collected.
- Determine costs for the implementation of this type of system.
- Future application in other places with similar climatic characteristics, such as the town of Cirminuelas.

2. Methodology

The section describes the methodology used to design and assemble the prototype for the collection of fog water, and the experimental process carried out in the work area that allowed the collection and measurement of water volumes. Figure 1 describes the phases of development of the work.

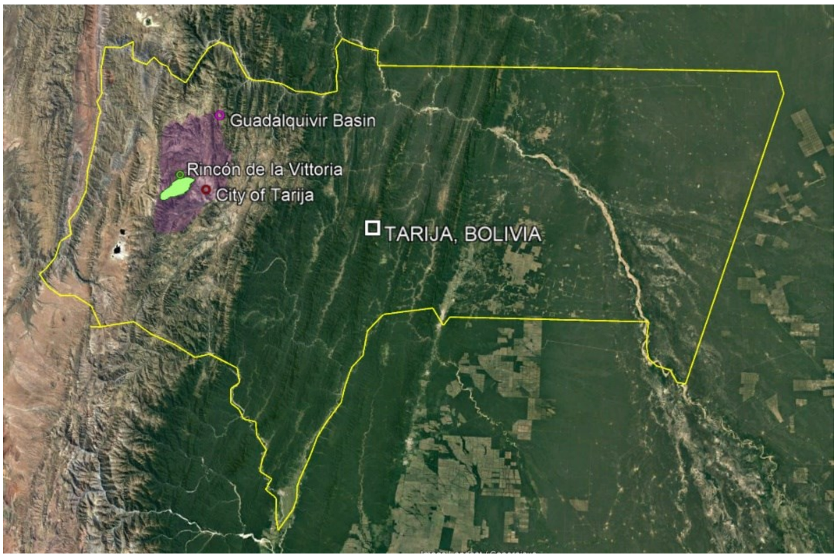
Figure 1: Project development scheme



2.1. Study area

The project was carried out in the town called "Rincón de la Vittoria," belonging to the Municipality of San Lorenzo, located within the Guadalquivir basin in the department of Tarija, Bolivia. Figure 2 shows the location of the study area. It has an approximate extension of 61 km^2 and a population of 216 inhabitants.

Figure 2: Location of the urban area of the municipality of Tarija



2.2. Design, assembly, and implementation of the prototype

For the present investigation, it is defined to design a prototype system for harvesting or capturing fog water in a flat configuration, which allows for making larger structures according to the desired amount to store.

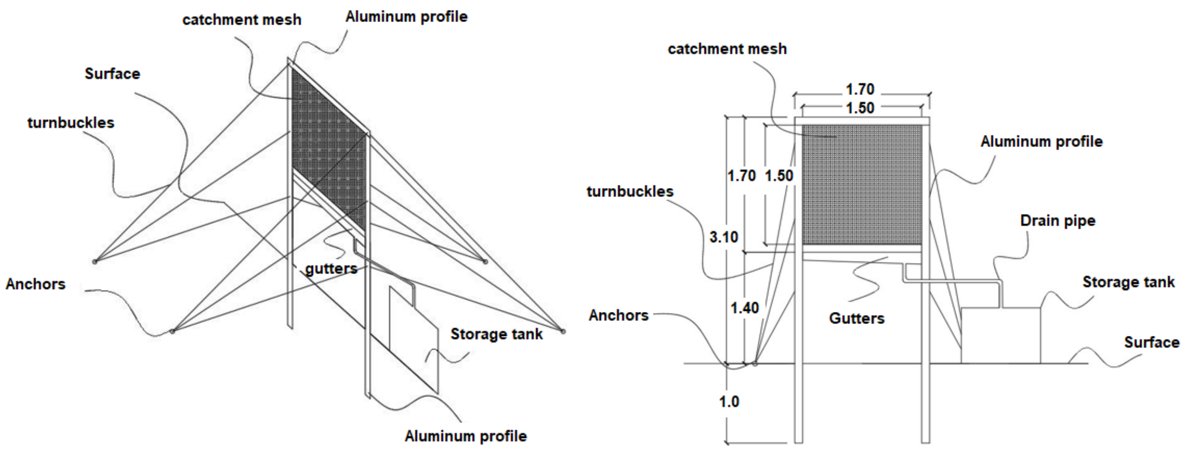
2.2.1. Configuration and characteristics of the prototype

The equipment is designed with an aluminum structure lined with a double layer of 1.5 $m2$ polyethylene at the height of 2.5 m from the surface level. Accounts with aluminum profiles buried at 0.5 m allow the meshes to be firmly supported. For the collection of fog water, it has a 10 cm wide iron gutter and a 2" PVC pipe that will carry the water to the 600-liter storage tank. Figure 3 illustrates the detail of the construction.

2.2.2. Measurement of collected fog water

The experimental work was carried out for 45 days. The data were collected daily, and the average volume obtained from the water collection was calculated.

Figure 3: Detail of the water harvesting pilot model



Source: Baldiviezo, R. (2021)

3. Results and discussion

The results of the experimentation are detailed below.

3.1. Assembly of the prototype and start-up

The assembly and start-up of the fog water collection prototype are shown in Figure 4.

Figure 4: Prototype assembled and working

Source: Baldiviezo, R. (2021)

3.2. Analysis of the volume of water collected

The system comprises a polymer mesh placed in a frame of 1.5 m2. The double-layered mesh is connected to a gutter and a 2" pipe, installed in a 600-liter tank that allows water to be stored. The water collection work was carried out between September and October, representing the beginning of the wet season in the basin.

The data collected during the 45-day collection process is illustrated in Table 1, and figures 5 and 6 show the daily behavior of the fog water collection process.

Table 1: Volume of water collected during the experimental phase

Month	Days	Liters (L)	Month	Days	Liters (L)
SEPTEMBER	5	15.2	OCTOBER	1	9.5
	6	7.1		2	9.7
	7	18.2		3	10.3
	8	8.4		4	10.6
	9	9.5		5	10.2
	10	9.1		6	11
	11	8.6		7	10.8
	12	11.5		8	11.8
	13	1.5		9	11.5
	14	8.8		10	10.3
	15	8		11	10.6
	16	8.8		12	11.5
	17	8.7		13	12.2
	18	8.2		14	10.2
	19	8.5		15	12
	20	7.3		16	11.8
	21	8.3		17	10.9
	22	8.5		18	12.7
	23	9.3		19	12.5
	24	8.5		20	11.5
	25	11.7			
	26	12.1			
	27	13.5			
	28	15.4			
	29	13.7			
	30	13.1			

Figure 5: Behavior of water collection in September

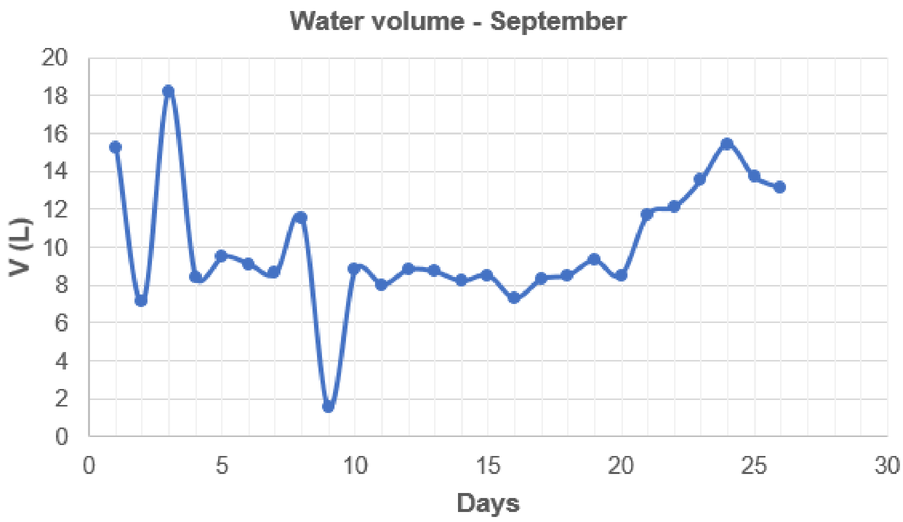
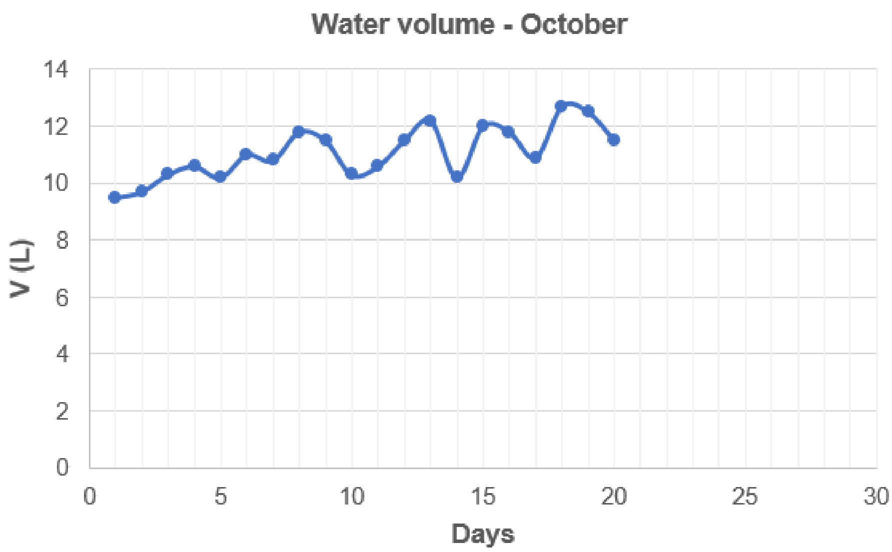


Figure 6: Behavior of water collection in October



The data in Table 1 and Figures 5 and 6 show no stable behavior in September because that month is the transition from a dry season to a wet one, where the days are variable in terms of temperature and humidity. However, the behavior of October shows more excellent stability and more evident trends.

Table 2 and Figure 7 show the daily behavior of the water collection process. The behavior represents a typical day in the study area for the month of October.

Figure 7: Daily behavior

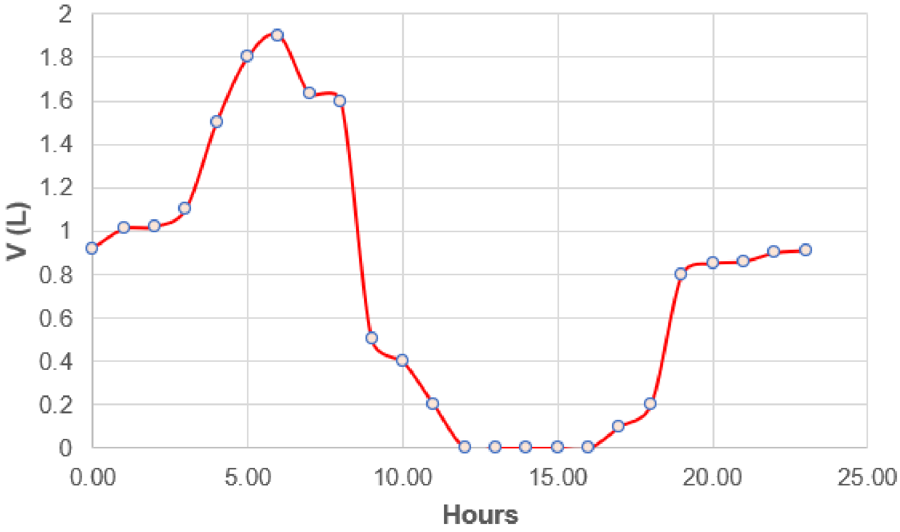


Table 2: Daily behavior in water collection

Hours	Liters (L)
0.00	0.92
1.00	1.01
2.00	1.02
3.00	1.1
4.00	1.5
5.00	1.8
6.00	1.9
7.00	1.63
8.00	1.6
9.00	0.5
10.00	0.4
11.00	0.2
12.00	0
13.00	0
14.00	0
15.00	0
16.00	0
17.00	0.1
18.00	0.2
19.00	0.8
20.00	0.85
21.00	0.86
22.00	0.9
23.00	0.91

The data and the figure show that during the first hours of the morning, that is, between 2 and 8 in the morning, is the time when the greatest water intake is in the study area, decreasing during the day.

3.3. System efficiency and future actions

The results show that the prototype of 2.25 m2 of effective collection area can collect approximately 483 l or a daily average of 10.5 l/d, with an efficiency of 4.7 l/d/m2 of the collector.

Considering that the minimum requirement per family is 80 l/day, a fog water collection system per family member of 18 m2 can solve the drinking water problems for food and hygiene.

As future actions, the project can analyze its efficiency at other times of the year, carrying out hybrid systems between collecting fog water and direct rainwater or through the roofs of the houses.

3.3.1. Future application in the town of Cirminuelas

Cirmimuelas, located in the central Valley of Tarija, is a town with significant social vulnerability due to the lack of various services, drinking water being one of the most important and scarce in the area.

The water and climatic conditions of Cirminuelas are very similar to those of Rincón de la Vittoria, where water scarcity and its vulnerability to climate change are the most important factors.

In addition, Cirminuela has similar climatic characteristics where foggy conditions are observed at the same hours as in Rincón de la Vittroia.

This makes it possible to point out that it will be possible to implement a fog water collection system in Cirminuellas with hydraulic and economic feasibility, contributing to reducing water scarcity in families in the area.

As the topographic, climatological and population conditions are similar to those of Rincón de la Vittoria, the implementation of the studied prototype in the Cirminuellas community will not have a change in the design scale or in the implementation costs.

4. Conclusions

The locality of "Rincón de la Vittoria," belonging to the municipality of San Lorenzo in the department of Tarija, Bolivia, presents drinking water shortages.

The experimental process of the research project shows that the fog in the study area has optimal characteristics to generate volumes of water that can be used to mitigate the water deficit.

The prototype designed, assembled, and put into operation in the study area shows that up to 10.5 l/d can be captured, equivalent to 13% of the minimum required by a family in the area. This makes it possible to mitigate and considerably lower the drinking water requirement for domestic use.

It is estimated that an approximate cost of 133 \$us/m^2 for the collection system.

To achieve a collection of 80 l/day, at least 18 m2 of installation of the collection system is required per family.

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