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LOS ATRAPANIEBLAS COMO FUENTE ALTERNATIVA DE AGUA DE BAJO COSTO EN LAS ZONAS DESÉRTICAS COSTERAS DEL PACÍFICO.

FOG WATER TRAPS AS A LOW-COST ALTERNATIVE SOURCE OF WATER IN COASTAL DESERT AREAS OF THE PACIFIC.

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RESUMEN

La escasez de agua es el concepto más común asociado al desierto. El desierto de Atacama es mundialmente conocido como el desierto más árido de la Tierra. A pesar de esta aridez, hay comunidades que viven en esta región y necesitan agua para subsistir. Esto ha llevado a la búsqueda de métodos alternativos para obtener agua, como el uso de atrapanieblas. Estos dispositivos capturan la humedad de la niebla, aprovechando un fenómeno regional conocido como Camanchaca. Durante el año 2015, se realizó la construcción de unidades de atrapanieblas en un cerro del sector Falda Verde en Chañaral (Norte de Chile). En el diseño de estas nuevas unidades de atrapanieblas, se consideró mejorar el sistema de anclaje y la distribución y ángulos de los tensores de apriete para que la estructura pudiera soportar las velocidades máximas de viento que se han registrado en la zona. Durante un año, se midió la cantidad de agua recolectada por estas unidades, obteniendo un promedio de 22 litros de agua/m^2 al mes.

Palabras clave: Captador de agua de niebla; malla de polipropileno; desierto de Atacama; colectores ecológicos; fuente de agua.

ABSTRACT

Water scarcity is the most common concept associated with the desert. The Atacama Desert is worldly known as the aridest desert on Earth. However, some populations are established in this area, requiring water for living, which promotes the search for alternative water sources, as fog catchers taking in advance of the regional fog event known as Camanchaca. During 2015, fog trap units were constructed on a hill in the Falda Verde sector in Chañaral (North Chile). In the design of these new fog trap units, it was considered to improve the anchoring system and the distribution and angles of the clamping tensioners in order that the structure could withstand the maximum wind speeds that have been registered in the area while recording the water accumulated by these units during a period of 12 months determined an average catchment of 22 liters of water/m^2 per month.

Keywords: Fog water catcher; polypropylene mesh; Atacama's Desert; environmentally friendly collectors; water source.

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INTRODUCTION

The fog or mist is a geophysical and geographical phenomenon that occurs in almost all areas of the world. In the Chilean territory, fog is frequent on the coast and high Andean mountains. It is defined as a mass of air composed of tiny drops of water (1 to 40 microns), which because they are so light do not fall, but remain suspended at the mercy of the wind if they are on the surface of the continents or oceans, while if they are in the atmosphere, they are called clouds (Cereceda et al., 2008).

One of the causes of the formation of clouds and fog is due to the presence of anticyclones or high-pressure centers. The Southeast Pacific Anticyclone is present off the coasts of Ecuador, Chile, and Peru. This produces a thermal inversion by subsidence, that is, air descending from the upper atmosphere that is heated by compression. This is due to the adiabatic heating of the intermediate layers of the atmosphere, caused by the downward movement of air from the high-pressure centers (Henderson-Sellers and Robinson, 1986).

The capture of fog water uses a simple and sustainable technology, whose implementation has been increasing in recent decades in different regions of the world (Olivier, 2002; Mousavi-baygi, 2008; Fessehaye et al., 2014; Carrera-Villacrés et al., 2017).

On the coast of the province of Chañaral, Atacama Region, Chile, fog occurs daily on the southwestern slope of the Pan de Azúcar National Park, with an hourly frequency that varies depending on seasonality. In these sectors, the construction of fog catchers was developed by an organization initially formed by local fishermen. In the sector, an average fog water catchment of 1.46 L/m^2 per day was determined by Larraín et al. (2002), which aroused interest in the development of mist water collection techniques in the area of Falda Verde.

The aim of the current study was to determine the best parameters for the construction of fog catchers in Antena 2 (Chañaral, north Chile) to obtain the greatest volume of fog water according to winds in the study area. Fog water was monitored for a year to observe the efficiency improvement of the low-cost collector systems.

MATERIALS AND METHODS

STUDY AREA: CHAÑARAL COAST FOG FEATURES.

The mist present on the coast of Chañaral is formed by the orogenic advection process. This is very common in the coastal cordons of northern Chile; it is formed from a stratocumulus cloud that is generated in the sea hundreds of kilometers from the coast. It remains practically constant presence, but variable in altitude, approximately between 500 and 1200 meters above sea level. This cloud is displaced by the wind from the sea to the coast and the Cordillera de la Costa (advection). There it is intercepted by the slopes and summits of the cliffs and hills, transforming into the fog, which is why it is defined as a "cloud at ground level" (Cereceda et al., 2008). In fact, the elevation between the coast of Chañaral and the summit of the hill Falda verde is 1000 m above sea level, which allows the capture of fog water.

According to the Chilean Navy Meteorological Service winds chart, the coast of the Chañaral province has a predominance of southwesterly wind, with average speeds of 10 knots, reaching a maximum of 40 knots. The speed or force of the wind is the main factor that influences the greater or lesser potential of fog water collection. In general, this is explained in that while there is more wind, more water droplets will pass through the mesh that intercepts the fog, which will be collected by said surface (Regalado and Ritter, 2016, 2017).

The mountainous ground of the Falda Verde hill is composed of sedimentary and igneous qualification rocks. The slope of the top of the hill has an angle of 40°. The slopes have great importance as a determining variable of the water collection. First, they define the trajectory of the winds, which in turn influence the arrival of cloudiness in the mountains. Second, they determine the feasibility of installing fog catchers in their peaks (Cereceda et al., 1992). Another additional component of the slope of the hill is the contribution in kinetic energy that is obtained with the height difference between the summit and the slope of the hill. This allows the energy saving of three pumps of 2.5 HP, which could contribute to a culture system with non-conventional renewable energy.

DESIGN AND CONSTRUCTION OF FOG CATCHERS.

Each double unit of fog catchers (two cloths of 6 m length each) was designed for a capacity to generate 1.46 liters of water per square meter of mesh (Fig. 1). This water catchment system was installed on a summit of the Antena N° 2 Falda Verde hill, on a hill surface with a maximum inclination of 40°. The fog catchers were oriented in such a way that they could receive frontally the predominant SW wind in the area.

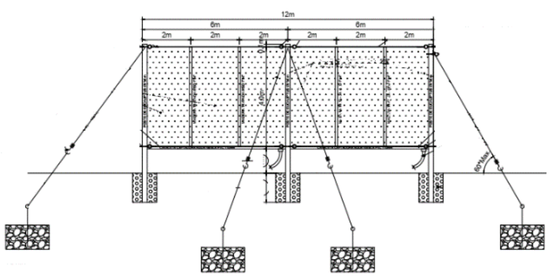

Figure 1: Design for the construction of the Falda Verde double trap unit. Source: Own elaboration.

POLE FOUNDATIONS AND TENSION ANCHORS.

The supports of each fog trap cloth were established in foundation dies based on soil-cement and boulders with a proportion of 50% stones and 50% cement floor, whose materials used corresponded to those available from the same hill and with a minimum dosage of three bags of cement per cubic meter of soil. The foundation for the tension anchors and winds (galvanized steel cables) was constituted of buried gabions with the same soil-cement and boulders filling in the same previous proportion.

SUPPORT PILLARS.

As supporting pillars for each double trapping unit, 150 mm diameter x 6 m height wooden poles were used located in line and every 6 m between them, which were covered on all sides with a layer of asphalt primer (Igol Primer®) and two waterproofing paint finishing layers (Igol Denso®). Each pillar of support was buried at a minimum of 0.75 m deep, thus guaranteeing a meter of height measured from the ground for the placement of the mist water receiving gutter and 4 m high, after the gutter, for the installation of Raschel mesh (polypropylene mesh).

FOG WATER COLLECTION SYSTEM.

The water collection system consisted of a polypropylene mesh, Raschel brand Coresa® brand of 50% shade coefficient and double layer, which has protection against UV radiation and useful life of approximately ten years. The dimensions of each cloth were 4 x 6 m, internal measurements of the frame; the polypropylene fiber of the mesh used was 1 mm wide. This mesh was woven in a triangular pattern with spacing between the horizontal lines of 1.3 cm. The mesh was placed horizontally tense and the fibers of the triangular patterns in a vertical plane. The mesh was supported in its upper and lower part by galvanized or stainless-steel cables covered by 125 mm diameter polypropylene and was sewn with both the upper and lower cable, using polypropylene yarn of 2 mm diameter.

WOOD SUPPORTS.

Treated and dimensioned wood of 25 x 100 mm, two per cloth of fog catchers. This wooden reinforcement was located 1 m above the ground at the most unfavorable point. The bolts that were used as support and union of the vertical frame table of the mesh were 125 x 250 mm hot galvanized steel, separated from each other by 1.25 m. The vertical supports of the Raschel mesh that were used to form the vertical frame of the fog catchers were treated wood of 25 x 100 mm. In the central post, supports were installed in duplicate. The mesh, prior to its placement, wrapped the board with one turn and was secured by a seam with a 2 mm polypropylene thread. The tables were installed with the function of keeping the Raschel grid fixed vertically.

The wood was protected against moisture on all sides with a layer of asphalt primer (Igol Primer®) and two layers of waterproof paint finish (Igol Denso®) to prevent its rapid deterioration by being exposed in an open area.

TENSIONERS.

The horizontal tension cables that were used to form the frame with the vertical boards were galvanized steel 9.5 mm coated with plastic-type PVC. These, at one end, considered a 125 mm hot-dip galvanized steel tensioner like all tension cables. At intervals of 2 m (one third) in the total length of the fog-trapping cloth, a vertical reinforcement was included hanging from the upper and lower tensioner cables, equal in length to the mesh. In each extreme pillar of the fog catchers, a support of 3 tensioners of galvanized steel of 8 mm with a plastic coating of the factory, connected by the superior part of the post was incorporated. In the central pole, 4 tension cables were used (two to windward and two to leeward).

The tensioning cable was connected to the connection element with the base, anchoring by means of a galvanized tensioner 125 mm hook - eye for 125 mm steel cable. The cable ties to the tensioner that were used were by turn by the eye and two galvanized steel clamps for 8 mm cable.

FOG WATER RECEPTION CHANNEL.

Immediately below the mesh, the channel of reception and pre-accumulation of mist water was located. The gutter that he used was made of hydraulic PVC-C10 material, of semicircular shape with a cross-section of 110 mm in diameter, open throughout its length and supported by the galvanized steel cable of 9.5 mm corresponding to the lower frame of the catch fog. The gutters were joined with PVC adhesive type Vinilit® 101 which considered caps on both ends of it and for each channel cloth. The windward side of the gutter was placed 2 cm in front of the frame and at the same height as the lower edge of the frame. The back part of the gutter extended 8 cm behind the frame to catch the drops that could be detached from the frame in strong winds. The distance between the ground and the receiving channel of mist water was maintained at a maximum 1 m high above ground level. The bottom line of the gutter was maintained with a slope of 1 % to drain the water to one end, where an opening and discharge was installed with connection to a 50 mm diameter of HDPE pipe. This design allowed the gutter to collect all the fog water and the drizzle that hits the fog catchers, having a substantial front area that can act as a direct collector of rain and drizzle.

CHANNELING SYSTEM AND TRANSPORT OF FOG WATER.

In the water conduction from the gutters to the sedimentation chambers, a 50 mm HDPE pipe was used, and it was used to transport the water from the chambers to the accumulation system at the foot of the hill. Special care was taken in the joints of the pipes to avoid leakage losses. The fog water transport system was constituted by 3 polypropylene drums with bolted cover, each of 50 L capacity and connected to each other by the HDPE pipe. These drums were distributed along the slope of the hill as sedimentation chambers, until reaching the mist water accumulation system located at the base of the hill. Each drum had an entrance through the top of the drum, 5 cm below the level of the lid and with a discharge elbow. The water outlet was located 18 cm above the floor of the chamber and included an elbow with removable polypropylene filter type Inox 55 x 80 mm, which retained particles of 1000 microns, at the vertical entrance of the elbow. In each of the drums, a Utype ventilation of minimum 25 mm in diameter was considered; this had a bronze or stainless-steel mesh at the outer end to prevent the entry of vectors into the drum.

RESULTS AND DISCUSSION

As populations increase and conventional water supplies are overexploited or contaminated the problem with the demand for freshwater globally will continue to grow (Schemenauer and Joe, 1989). The demand for freshwater has many political, social, and economic problems, The World Health Organization (WHO) and the United Nations Children's Fund (UNICEF) now estimate that, although progress has been made, 605 million people worldwide will still be without access to safe drinking water in 2015 (WHO, 2012).

An alternative source of water is the fog or mist, used extensively in ancient times but largely ignored by water provision authorities (Olivier 2002). Many experiments have been conducted indicating the considerable potential of fog as a water source.

In South Africa, during 1969/70, Schutte (1971) implemented two large fog screens, constructed from a plastic mesh, and measuring 28 x 3.6 m each, were erected at right angles to each other and to the fog- and cloud-bearing NE and SE winds. During a 15-month period, from October 1969 to December 1970, the screens collected an average of 31,000 L of water per month i.e. approximately 11 L/m^2 d. In another study, run in northern Chile in 1987, 75 fog collectors, each measuring 12 x 4 m were erected on a hill. According to reports, production rates vary from zero on clear days to a maximum of 100,000 L/d (Schemenauer et al., 1988; Schemenauer and Cereceda, 1992, 1994).

Previous data from the same study site found that the monthly water yield could be as high as 43.8 L/ m^2 of collecting surface (Larraín et al., 2002). Meanwhile, in our results, the measurement of fog water collection has been made from August 2015 to July 2016, with volumes ranging from 0 to 9,000 liters per month. The months of absence of catchment were January and February of 2015, while the highest monthly collection was in the month of August 2015. The average monthly fog water collection was 22 L/ m^2 (Table 1).

2015					2016						
Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul
9000	5000	6000	5600	5000	-	-	2000	8000	4900	4300	2000

Table 1. Fog water collected (in L/month) in the sector of Falda Verde, Chañaral (Atacama's Region). Source: Own elaboration.

Larraín et al. (2002) reported average rates of uptake between 1.4 to 8.3 l/day/m^2. The average measurements obtained were approximately 5 l/day/m^2. Assuming that the collection efficiency of the fog catcher that was used is 20%, an optimized fog catcher should have around 6% more efficiency, so it could capture 50% more of the water that is capturing 8 l/day/m^2 maximum (on average per year). Because of this, places with collection rates of 8 l/day/m^2 could capture on the order of 12 l/day/m^2 with an optimized fog catcher. In general terms of the average collection rates (between 5 and 8 l/day/m^2 annual average) and fog collection efficiencies (between 20% and 30%), it can be deduced that the flow of fog that passes through a square meter without fog catcher is between 25-40 l/day/m^2 , so the quantitative analysis will be carried out between the collection ranges between 5 and 40 l/day/m^2 as a maximum limit (40 l/day/m^2 would imply capturing all fog flow).

In terms of innovation, prototypes of fog catchers can be used for new prospecting studies for the provision of water. This contributes to the generation of technical alternatives for the provision of rural drinking water that depends on tank trucks (a highly inefficient condition for the States). In this way, desert regions can set objectives to improve water availability in sub-territories that demand stability in consumption and agricultural development and that do not have the possibility of connecting to APR (Rural Drinking Water) systems, covering a need basic.

CONCLUSIONS

The current technology represents a significant risk investment, but the pilot project presented here, first carried out to quantify the potential rate and yield that can be anticipated from the fog harvesting rate and the periodicity of the fog within the area, showed great potential.

Despite this, it is important to care not only with yield but with the water quality too. In recent analysis (Bonnail et al., 2018) fog water has failed to meet drinking water quality standards because of some minerals derived from the mining sector.

Water scarcity problem urges to map an atlas that shows an alternative source of water. So, to be this possible is necessary for planning the use of land without risk by exposing current water resources.

In the technological field and development of new knowledge, prototypes of fog catchers installed in desert and arid areas can generate the spatial identification of new sources of fresh water based on fog. Thus, according to the Oslo Manual, innovation implies the use of new knowledge or a new use or a combination of existing knowledge (OECD and Eurostat 1997, page 46 letter d) we can say that fog catcher prototypes allow:

- Expand the scope of research from new areas with potential presence of fog to the rest of the countries.
- Be a technical reference for the development of advanced human capital in the regions that implement it, so that the new generations of professionals, technicians and trade personnel who operate in the territory can develop competencies and skills based on innovation as well as happened in Chile with photovoltaic systems and the growth of investments in the non-conventional renewable energy sector as the basis of the decarbonization process. Now, based on the knowledge to be developed, the development of new technologies for capturing the fog phenomenon is planned, considering that currently in Chile this technology is in the initial stage.

In terms of territory and legality, Chile, like most countries in the world, does not have the use and exploitation of water from fog regulated within its legal regulations. Therefore, this tool allows laying the technical foundations to enable the development of a legal framework, facilitating:

- Establish a baseline for the use of fog as a supply of fresh water to rural communities located in the country.
- Consolidate as a technological input for the definition of public investment in Rural Drinking Water (RWA) systems prioritized by the sectoral ministries of Public Works, Interior and Agriculture.
- Contribute with technical information, related to the presence of fog, for the 6 strategic planning instruments of the region.
- Consolidate an additional technical variable that contributes to the private investment decision by productive sector of the Atacama region and the country: mining, financial services, construction, agriculture, tourism, metalworking, aquaculture, among others.
- Cloud catcher technology can be used by public entities to substantiate the requirements of Law 19,300 on General Environmental Bases, in articles No. 7 bis, 8 and 9, which states that regional Territorial Planning plans must always be submitted. a strategic environmental assessment explicitly incorporating environmental objectives and effects of the instrument.
- Support the determination of organizations in compliance with Constitutional Organic Law 19,175 on Regional Government and Administration, updated in 2018 and with a projection of exercise in regime starting in 2019, which indicates that the PROT is established as a binding instrument in the making private and public investment decisions throughout the country's territory. In this way, Qinyaku is a technical support of the binding PROT, since it can contribute to recognizing the areas that have been placed under official protection, in accordance with the provisions of the respective legislation, for their environmental value, whether natural or cultural, as well as the zoning of the coastal edge of the region, considering possible future modifications.
- Incorporate its use in the updates of the National Policy for the Use of the Coastal Edge of the Coastal Edge, which is defined as strategic guidelines applied to a special geographical strip of the national territory that includes public beach lands, the beach, the bays, gulfs, straits and internal channels, and the territorial sea of the Republic of Chile.
- Support as a technical tool the making of strategic decisions in the pre-feasibility process of investment projects by supporting the identification of geophysical prospecting methods aimed at those areas with the best hydrogeological aptitudes, to facilitate the implementation of collective rural drinking water systems.
- Become a public good due to the strong connection with matters of improvement in the quality of life of citizens by allowing the growth of the country to be planned with a horizon of 40 years. In this way, the ministries and public services that are in the territory can have a new variable (the availability of new sources of fresh water) that is added to the traditional methods and instruments that are applied from the set of social values, national and regional political orientations, and the economic and

environmental conditions of the territories, which have been contained in the respective Regional Development Strategies.

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Conflicts of interest/Competing interests
The authors declare no conflict of interest. The funders had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript, or in the decision to publish the results.

Ethics approval
Not applicable

Consent to participate
Not applicable

Consent for publication
Not applicable

*Availability of data and materia*l
All data and information were archived under reports by Regional Government of Atacama, Chile.

Code availability
Not applicable

Authors' contributions
Conceptualization, R.C.L. and L.P.M.V.; methodology, L.P.M.V.; validation, R.C.L., C.G.A. 7 and E.B.; formal analysis, R.C.L.; investigation, R.C.L.; resources, C.G.A.; data curation, R.C.L.; writing—original draft preparation, R.C.L.; writing— review and editing, E.B.; visualization, L.P.M.V.; supervision, L.P.M.V.; project administration, R.C.L.

Supplementary Materials
Video S1: Fog being trapped in Falda Verda hill after installation of technical improvements.

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