

- *Fog collection – Polypropylene mesh – Fog variability – Rural water supply – Colombia*

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Fog Collection Variability in the Andean Mountain Range of Southern Colombia

Variabilität der Nebelwassersammlung in den südlichen kolumbianischen Anden

With 5 Figures and 2 Tables

The spatial and temporal fog collection variability and the potential use of fog as an alternative source of water supply were evaluated in southern Colombia by means of fog collection experiments. Twelve Standard Fog Collectors (SFC) were installed in a mountainous zone, based on topographic and fog formation conditions. Different shade coefficients were evaluated, ranging from 1,680 to 1,850 m a.s.l. Results indicate a high potential for the use of fog to meet water requirements in rural areas. Data collection and analyses covered both dry and rainy seasons. Annual average collection rates amounted to 4.2 l per m² per day for precipitation + fog, and 3.3 l per m² per day for fog only. The most important month for collection was June with 5.3 l per m² per day for precipitation + fog, and 5.0 l per m² per day for fog only in dry days.

1. Introduction

Regional hydrological droughts occur naturally in some mountainous zones of the Colombian Andean watersheds. These events have negative consequences in terms of water availability in rural areas, both for human consumption and for agricultural purposes (*Molina 2007*). Such associated water scarcity in several regions of the Andean mountain range of Colombia is aggravated by an advancing deforestation of the

native highland forests, product of the expansion of the commercial agricultural frontier (GWP 2000), and of the growth of illicit cultivations which are managed by drug trafficking cartels. According to the United Nations, continuous coca and poppy farming in Colombia has had a detrimental effect on the environment, leading to an annual average loss in recent years of more than 200,000 hectares of native forest (*Calvani 2007*). In addition to these factors that potentially worsen the water availability in the region, the

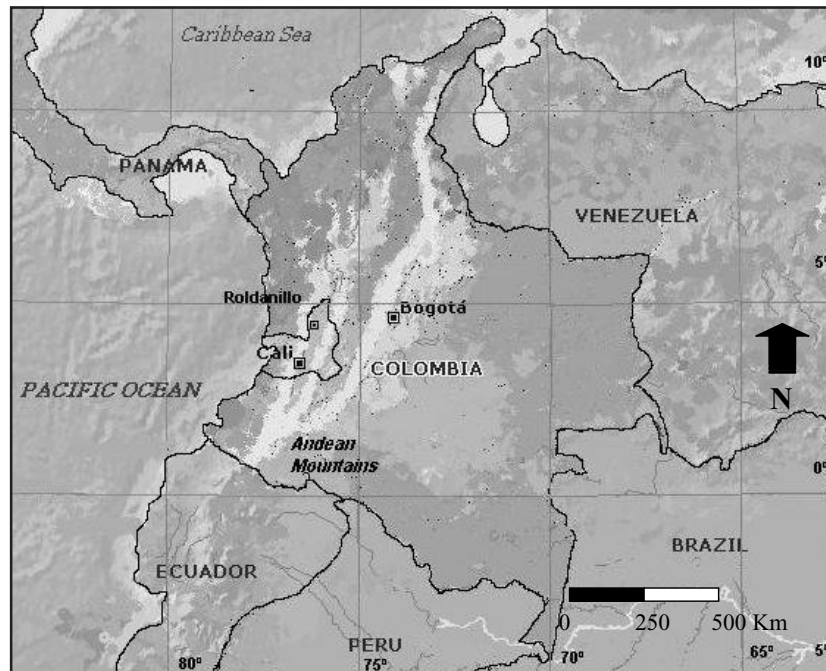


Fig. 1 Location of the study zone: near the municipality of Roldanillo, in the Andean mountains of southern Colombia
 Lage des Untersuchungsgebiets: nahe der Stadt Roldanillo in den Anden im südlichen Kolumbien

use of surface water sources is sometimes restricted by chemical pollution of springs and mountainous streams caused by the uncontrolled and inappropriate use of agrochemicals in agriculture (Molina and Escobar 2005).

Scarcity of surface water sources in mountainous zones could be managed partially by means of water from fog collection (Schemenauer and Cereceda 1994a). Water harvesting from fog could also be considered for arid and semiarid rural zones, not only in scenarios concerning water supply, but also as an option to get water of good physical quality or in instances where water treatment from surface sources is not feasible. However, basic chlorination treatment of water collected from fog should be considered for human consumption based on local and regional environmental policies. To date, the potential use

of fog water as an alternative for water supply has not been evaluated in Colombia. The main objective of this work is to study the spatial and temporal fog-water collection variability in a mountainous zone of Colombia. This paper presents analyses and results of a successful experiment with fog-water collection in the Andean mountain range of southern Colombia, where the collection material consisted of polypropylene meshes similar to those used in other experiments with Standard Fog Collectors (SFC) (Schemenauer and Cereceda 1994b; Cereceda et al. 1997). Other projects have been implemented in countries like South Africa, Namibia, Mexico, Nepal, Ecuador, Peru and Chile (Cereceda et al. 2000). An important reason for supporting and promoting the implementation of this appropriate technology is the need to look for alternative water sources in rural areas of southern Colombia.

2. The Study Region

The study area is located in a rural zone of the Andean Mountain Range of southern Colombia, near the municipality of Roldanillo, 200 km north of Cali (Fig. 1). It covers an area of approximately 500 ha. The altitude of the study region varies between 1,550 to 1,850 m a.s.l., and its topography is highly variable. The climate in this region is semiarid with an average total rainfall of approximately 600 mm/year. The more significant rainy period occurs during the months of April and May. The period January through March is the driest of the year with monthly rainfall averages below 40 mm; June-July is also characterised by low rainfall values with monthly averages below 47 mm. The annual average pan evaporation rate is approximately 5.1 mm/day and the annual average temperature is 21°C. The data source for this climatic description is provided in section 3.

Agriculture and stockbreeding are the main activities in the region. Although pasture for cattle breeding is predominant, some crops such as beans and a variety of sugar cane called *panelera* are grown on farms. Meat and milk production are affected by surface water variability and low water availability, especially during the dry periods of January-March and June-July. For this reason, farmers are forced to keep water in small artificial reservoirs during the rainy periods like November-December and April-May, for use in the dry months characterised by low rainfall. Irrigation activities are not carried out within the study zone. Water for human consumption is transported through plastic pipes from distant locations and it is obtained from surface sources with high contamination levels, including a high sediment concentration. Direct and subjective observations in the field suggest that the deficient quality of the water is the primary cause of gastrointestinal diseases, especially among the younger population under 5 years.

3. Materials and Methods

Climatic information mentioned in section 2 was provided by Corporación Autónoma Regional del Valle del Cauca CVC, a governmental agency and one of the environmental authorities in Southern Colombia (H.F. Aristizabal, CVC, personal communication 2005). For the study region described in section 2, twelve collectors were built from polypropylene mesh with a vertical collection surface of 1.0 m². The specifications and dimensions suggested by *Schemenauer and Cereceda* (1994b) were considered for the design of the SFCs, with some modifications (*Molina and Escobar* 2005): In order to take advantage of the availability of local material and to reduce fixed costs, bamboo posts, 4.2 m long, were used to support the collector frame, which stood 2.0 m above the ground. The base of each post was inserted into the ground to a depth of 1.0 m without concrete foundation.

Eight collectors used polypropylene mesh with a shade coefficient of 35 % and the other 4 collectors had a shade coefficient of 50 %. The mesh was placed on the SFC frame in a double layer, following the recommendations by *Schemenauer and Cereceda* (1994b). Both types of mesh were obtained at Santiago de Chile. Such mesh is manufactured by Marienberg S.A. (address: Exposicion 202, Santiago de Chile). The mesh is woven in a triangular pattern and, according to the manufacturer, it is UV-protected and has a lifespan of about ten years.

Meshes with two shade coefficients, 35 % and 50 %, were tested to compare water collection yields from fog and to approximate which shade coefficient had the best efficiency under study conditions. However, it should be noted that several studies have recommended the use of the 35 % shade coefficient. The double layer of mesh with the 35 % shade coefficient covers approximately 60 % of the surface area of the collector (*Schemenauer and Cereceda* 1994b). This leaves

about 40 % of the area open for the wind to pass through. The choice of the type of mesh with regard to the collection efficiency of the fog droplet sizes and wind speeds of interest, is a compromise between having a fibre of a width that will cover a large enough percentage of the surface area to generate sufficient water for measurement purposes (*Schemenauer and Joe* 1989) on the one hand, and not barring the fogwater away from the mesh. If too high a percentage of the surface area is covered by the mesh, the collector begins to act as a solid wall and the wind-carried fog droplets will pass around the collector.

On the ground of Los Arenales, a farm situated 12 km to the West of the municipality of Roldanillo, four locations were selected to carry out the experiment. At these locations with the local names of La Montañuela, El Eucalipto, Las Torres and El Trillo, six sites were chosen to develop fog collection measurements, and one pair of collectors per site was installed. Each pair of SFCs had the same shade-coefficient mesh. The two SFCs

were set up at a 90° angle between them because no historical information on winds was available for the zone to determine the best orientation of the collectors. Field measurements of wind were not recorded during the study period due to financial restrictions. The availability of historical records of wind (wind speed and its temporal variation, prevailing wind direction etc.) helps to determine not only adequate installation sites for fog collectors, but also their optimal orientation in experimental and operational projects (*Schemenauer and Cereceda*, 1994c). According to *Schemenauer and Joe* (1989), the most likely meteorological variable to influence collection efficiency is the wind speed. In this study, however, qualitative observations in the field in the two months previous to the installation stage of the SFCs indicated that prevailing winds blew from south to north. For all six sites, one of the collectors in each pair of SFCs per site was oriented perpendicular to the north-south direction. The SFC is a flat surface installed perpendicular to the prevailing wind direction during fog events (*Schemenauer and Cereceda* 1994b). The reason

Tab. 1 Standard Fog Collectors: geographical information, layout and type of mesh
Nebelwassersammler: geographische Angaben sowie Anordnung und Netztyp

Location	Site	Collector	Mesh	Altitude (m a.s.l.)	N	W
La Montañuela	I	1	50 %	1784	4° 27' 16.2''	76° 11' 44.6''
		2				
	II	3	35 %			
		4				
El Eucalipto	III	5	35 %	1817	4° 27' 33.2''	76° 11' 9.9''
		6				
Las Torres	IV	7	50 %	1838	4° 27' 44.3''	76° 10' 48.3''
		8				
	V	9	35 %			
		10				
El Trillo	VI	11	35 %	1715	4° 27' 55.6''	76° 10' 38.1''
		12				

for this is that the collection rate of water from fog per unit area is expected to be highest when the collecting surface is perpendicular to the prevailing wind direction; otherwise, its efficiency will decrease. For further discussion on the collection efficiency of fog collectors using polypropylene meshes, readers are referred to *Schemenauer and Joe* (1989). The other collector set up at a 90° angle is useful for future analysis and comparisons of collection yields at the site. *Table 1* presents data on the collector distribution and geographical information about the locations. Data on geographical coordinates and altitude were obtained by means of a GPS device. Sites I and II were 20 m apart, and sites IV and V had a distance of 15 m between them.

Four rain gauges were also installed in the study region, one for every location. Field measurements were initiated on 1 November 2003, with

daily data registration of fog collection and precipitation between 3 and 5 p.m. Although temperature and humidity were also measured on a daily basis, this paper only presents data and analyses related to fog-water and rainwater collection during the period November 2003 – February 2005. Further analyses investigated the monthly spatial variation of fog-water collection at an altitude above 1,600 m a.s.l. Thus, contours were generated by interpolating point values onto the grid nodes. The nodes corresponded to the locations where SFCs were installed and the point values corresponded to the monthly fog collection yields. Isolines of fog-water collection rates were estimated using Kriging as the interpolation method, by means of the 3D-Field software. The package and manuals of this software can be downloaded free from the internet (3DField Project 2007: <http://field.hypermart.net/index.htm>). Those SFCs with the highest

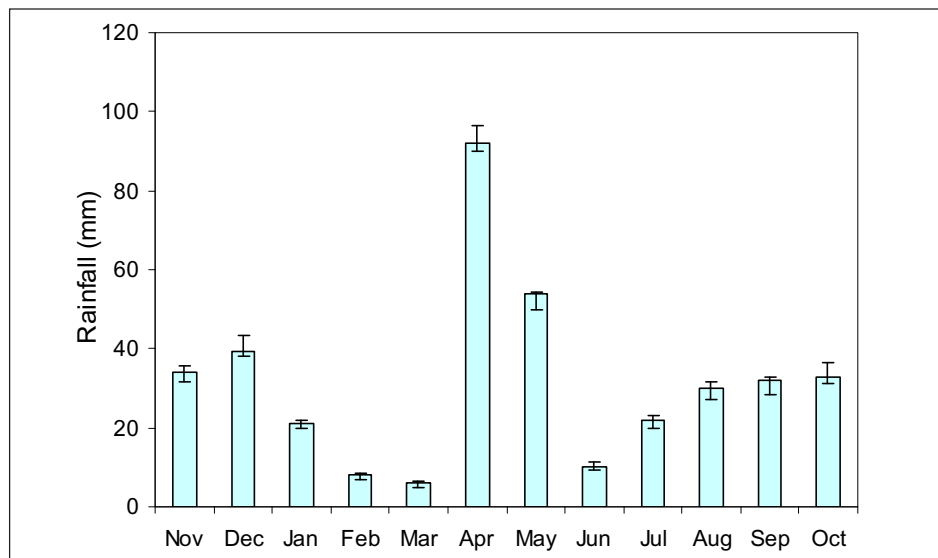


Fig. 2 Average distribution of monthly rainfall at the locations La Montañuela, El Eucalipto and Las Torres, 2003-2005. The whiskers depict the range of monthly rainfall at the 3 sites. *Durchschnittliche Verteilung der monatlichen Niederschläge an den Stationen La Montañuela, El Eucalipto und Las Torres 2003-2005. Die vertikalen Striche geben die Schwankungsbreite der 3 Stationen an.*

collection yields at each site were selected for the spatial analysis.

4. Results

In the following we present an analysis of both spatial and temporal variability of rainfall and fog-water collection, together with general insights and recommendations concerning the implementation of a future operational fog collection project in the study area.

4.1 Analysis of rainfall

Significant differences of rainfall were not observed when comparing La Montañuela, El Eucalipto and Las Torres, although La Montañuela presented a slight tendency to higher rainfall values. El Trillo was the exception, with

the lowest reported rainfall for the studied months, resulting in the driest study location and the lowest reported fog collection rates. *Figure 2* illustrates the average distribution of the monthly precipitation at the first three locations. It can be observed that the driest season occurred during the months of February and March, with precipitation values of 8 and 6 mm/month respectively.

In terms of the frequency of days with rainfall within each month, February, March and June were the driest months, with an average of 13 % of rainy days. April and May showed the same frequency (14 rainy days), but April had a higher amount of rainfall than May (*Fig. 2*). The rest of the months had an average of 28 % of rainy days. Since no long-term records of precipitation were available, we can only qualitatively state that interannual variability of rainfall frequency and amounts is high.

Tab. 2 Average fog + rainwater collection rates of the SFCs (Nov 2003 – Feb 2005), sorted by yield
Durchschnittlich gesammelte Nebel- und Regenmengen der SFCs (Nov 2003 – Feb 2005), sortiert nach dem Gesamtertrag

SFC	Monthly mean (l/m ²) over 485 days	Daily mean (l/m ²) over 485 days
10	124.5	4.15
9	97.8	3.26
7	90.3	3.01
1	83.4	2.78
8	70.2	2.34
2	58.5	1.95
3	51.6	1.72
6	25.5	0.85
4	24.6	0.82
5	17.7	0.59
12	6.3	0.21
11	5.7	0.19

4.2. Variation of fog and rainwater collection

With respect to the average of fog- and rainwater collection at each location during the period of observations, the Las Torres collectors presented the highest yields. This can be partially explained by the fact that this location has the highest altitude, as will be discussed later. Based on visual observations on the field (no measurements are available), the high wind speed at Las Torres is also a factor that improves fogwater collection efficiency (Schemenauer and Joe 1989). The locations La Montañuela, El Eucalipto and El Trillo follow in order of importance with regard to water yield from fog. Average fog + rainwater collection yield values are given in *Table 2* starting with the site that registered the highest values. These results show that the three highest collection rates correspond to collectors 10, 9 and 7, which were all installed at Las Torres. SFC 10 always had the highest rates, both in terms of fog + rainwater collection and ‘fog

only’ collection. SFC 1 at La Montañuela also showed a good yield, with 2.8 l/m²/day.

Figure 3 presents data of SFC 10, considering that it was the most efficient collector of this study, in particular the temporal variation in fog + rainwater collection (days with or without rainfall) and ‘fog only’ collection (days without rainfall). The best fog + rainfall collection yield occurred in June and September, with an average of 5.3 and 5.2 l/m²/day, respectively. This was mostly due to the contribution of fog. Similar analyses were also conducted for the other SFCs, where June and September also presented the best fog + rainfall collection yields.

The month of June deserves special attention as it presented the most favourable conditions for fog collection and possibly also for fog formation. Despite being one of the driest months in terms of rainfall depth (*Fig. 2*) and frequency of rainy days, June is the wettest month in terms of

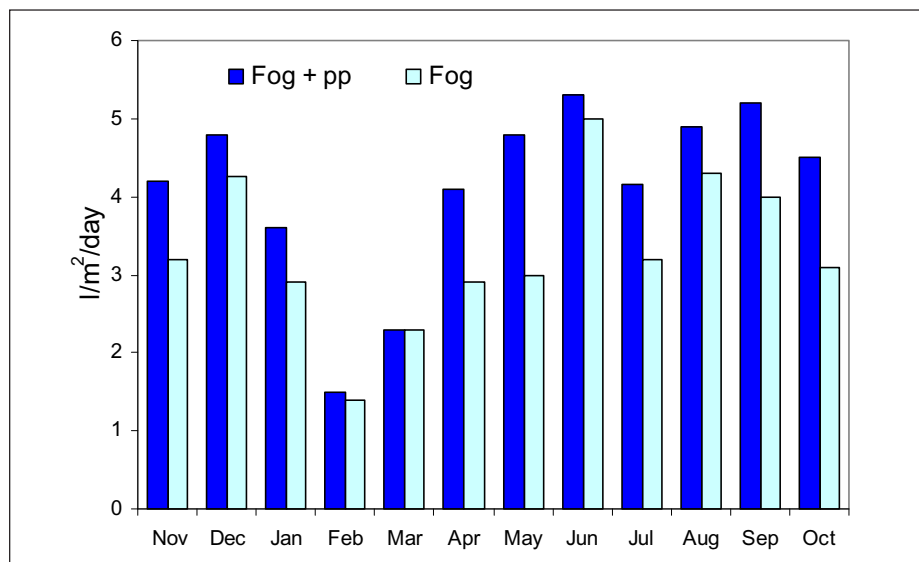


Fig. 3 Monthly variation in fog + rainfall collection (days with or without rainfall) and ‘fog only’ collection (days without rainfall) at SFC 10 / *Unterschiede bei den monatlich gesammelten Mengen an Nebel- und Regenwasser (an Tagen mit oder ohne Regen) bzw. nur Nebelwasser (Nebeltage ohne Regen) am Nebelsammler 10*

water harvested from fog, with the highest monthly average fog yield on dry days. When the most efficient collector of this study (SFC 10) is considered, the collection rate of water from fog only for the month of June was $5.0 \text{ l/m}^2/\text{day}$ (Fig. 3). Comparing this last value with the mentioned collection rate of $5.3 \text{ l/m}^2/\text{day}$ on days with rainfall + fog, it can be inferred that the difference of $0.3 \text{ l/m}^2/\text{day}$ corresponds to the average collection rate in June due to the rainfall/drizzle caught by the collector mentioned. Bearing in mind that there are 30 days in June, the rainwater collection in the SFC 10 amounts to 9.0 l/m^2 . Rainfall depth can be also expressed in units of volume per unit area (e.g., $1.0 \text{ mm} = 1.0 \text{ l/m}^2$). Therefore, measurements from fog collectors and

rain gauges can be related; the average rainwater collection rate of 9.0 l/m^2 for the SFC10 in June is equivalent to 9.0 mm . This value of water collection from rain is in some sense consistent with the 11.2 mm of rainfall recorded for this month at the rain gauge at Las Torres. For this specific case, it can be said, as an approximation, that the SFC 10 caught 80 % of the monthly rainfall/drizzle recorded in the gauge station. The analyses and discussions of related additional results, as well as the factors involved in the rainfall collecting process by standard fog collectors (rain droplet diameter, wind direction and speed, angle of fall of drops etc.), are beyond the scope of this study. What we can state qualitatively, and based on the study conditions, is that the test-

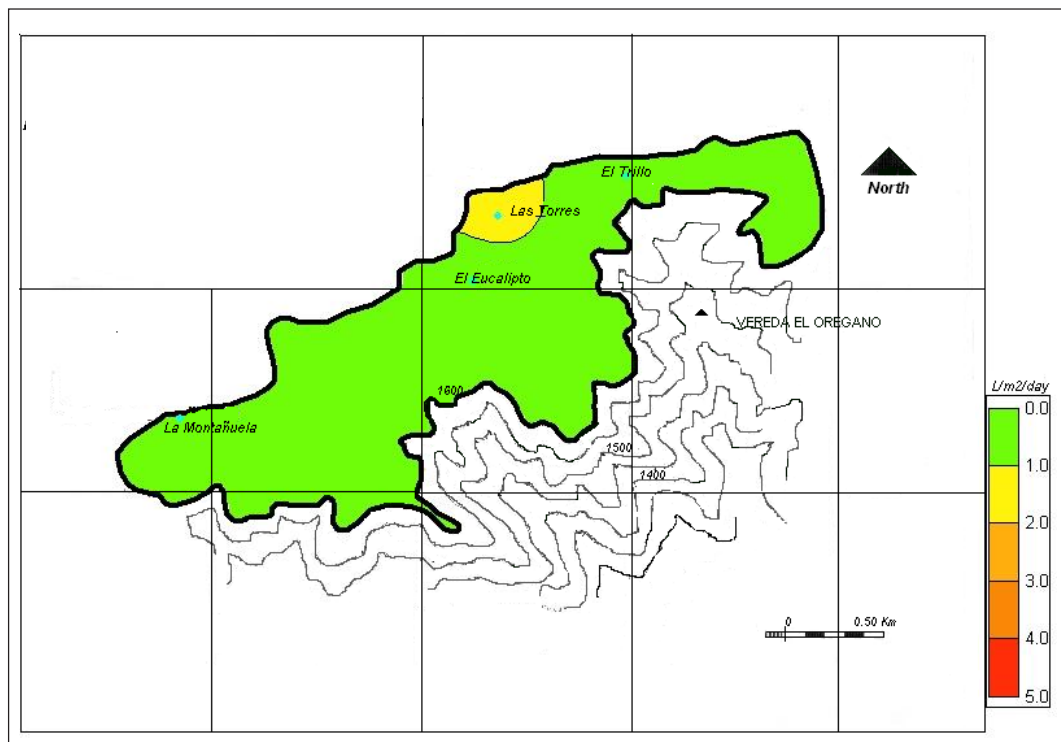


Fig. 4 Average spatial variability of fog collection for the investigation area at Finca Arenales, Roldanillo, February 2004 and February 2005 / Durchschnittliche räumliche Variabilität der gesammelten Nebelwassermengen im Untersuchungsgebiet Finca Arenales, Roldanillo, Februar 2004 und Februar 2005

ed fog collector can be also an effective device to collect rainwater in dry months like June. In our understanding, there is little research in the effectiveness of vertical mesh-constructed collectors to harvest rainfall (e.g., *Schemenauer and Cereceda 1994c*). This issue should be investigated further in the future.

Figure 4 shows the spatial variation of fog collection in February, the driest month of the study period in terms of water collected from fog. *Figures 4 and 5* also depict the contour lines related to the topographic characteristics of the study area. It can be observed that the highest average collection rate occurs at Las Torres, with values between 1.0 and 2.0 l/m²/day. *Table 1* shows that

this location has the highest altitude. Fog variability for June, the most productive month of fog for the period studied, is shown in *Figure 5*, with the highest average collection rate also at Las Torres, with values above 5.0 l/m²/day. Since the fog formation process in the study zone, and in general in the Colombian Andean Mountain Range, is mostly orographic, the highest altitude at Las Torres plays a very important role in obtaining the highest fog-collection yields. Because air mass lifting reduces atmospheric pressure and temperature, the air becomes more saturated; and as the adiabatic cooling increases, more condensation is produced (*Dingman 2002*). At this point, the wind effect (direction and speed) is also very important in harvesting the clouds. Wind speed

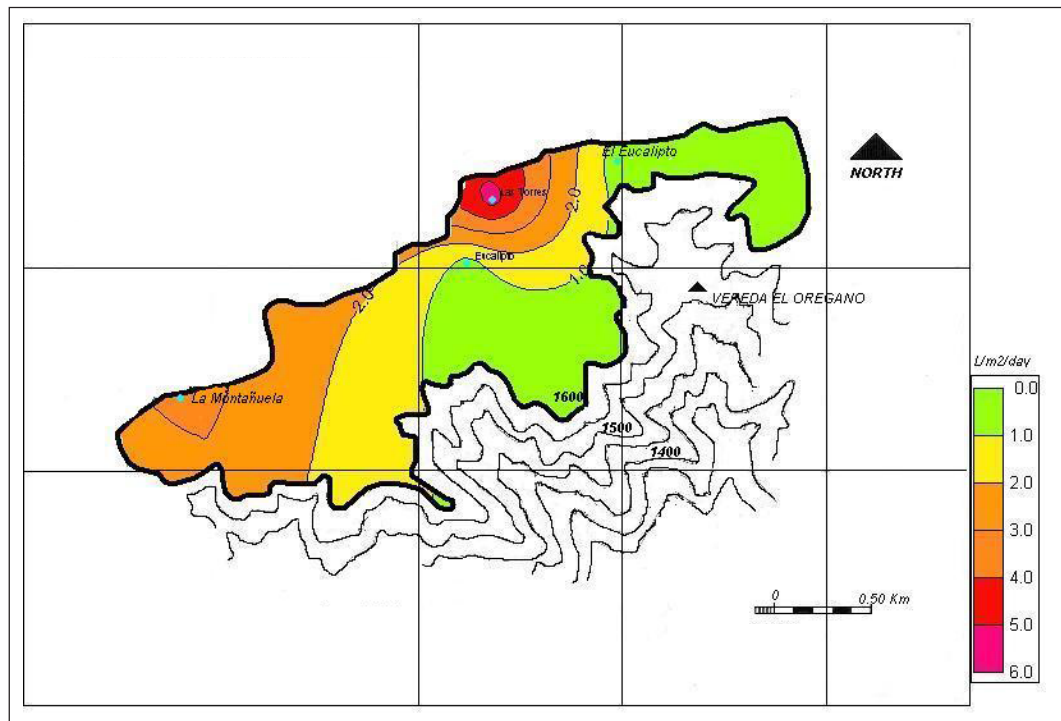


Fig. 5 Spatial variability of fog collection for the investigation area at Finca Arenales, Roldanillo, June 2004
 Räumliche Variabilität der gesammelten Nebelwassermengen im Untersuchungsgebiet Finca Arenales, Roldanillo, Juni 2004

becomes stronger at higher elevations than at lower ones due to the negative gradient of pressure produced by an air mass lifting. As wind speed increases towards Las Torres, the quantity of water collected from fog increases as well. On the other hand, wind direction is very important for fog harvesting. It is expected that the collection efficiency of water from fog is highest when the collecting surface is perpendicular to the wind direction. As mentioned in section 3, prevailing winds at Las Torres are from south to north – a situation that explains partially the spatial variation of fog collection shown in *Figure 5*. Here, a positive gradient of fog collection is observed towards Las Torres in the month of June, both from the south to the north and from the east to the west. Thus, installing meshes parallel to the southeast direction is another recommended orientation of collectors if June is the target season for harvesting fog. These findings allow appropriate decision-making for planning and implementation of a future operational fog collection project.

A final analysis performed on the two types of mesh with different shade-coefficients did not lead to conclusive results. At the La Montañuela location, the 50 % shade coefficient mesh was the most efficient in terms of collecting water from fog. However, at Las Torres, the 35 % shade coefficient mesh showed the best performance.

5. Discussion

The favourable collection rates observed in this experiment are consistent with results from other countries in the Andean region, where data from SFC tests have been analysed for similar time scales, i.e., collection data recording on a daily basis and for periods greater than or equal to one year. *Schemenauer and Cereceda (1994a)* reported average collection rates of 3.0 l/m²/day in Chile, 9.0 l/m²/day in Peru, and 12.0 l/m²/day in Ecuador. Such yields partially supported the decision-making and design processes in the implementa-

tion of successful operational projects. Recent results of fog collection projects in some of these and other Latin American countries are also reported in *Villegas et al. (2007)* and *Carter et al. (2007)*.

Similar experiments have been carried out – and some are still in operation – in Portugal (*Prada et al. 2007*), the United States (*Fernandez and Ruiz 2007*), Croatia (*Mileta 2007*) and Morocco (*Marzol and Sanchez 2008*). Experimental systems, not necessarily using SFCs for assessing fog collection, have also been installed in other countries like South Africa, the Dominican Republic, Spain, Cape Verde and Colombia. In the latter country for example, automatic fog gauges have been installed recently as part of the study of inputs by fog to the paramo systems (*Tobón et al. 2008*)

In a hypothetical scenario for a fog operational project to supply water to people in the study zone, based on an average monthly collection rate of 4.0 l/m²/day at Las Torres location, with 20 operational collectors of 50 m² each and installed in the ridgeline and parallel to the southeast direction, there would be a total estimated water yield of 4.0 m³/day. If we consider a per capita water consumption (domestic) in the study zone of 50 l/person/day (*Chapagain and Hoekstra 2004; Tehelen 2006; Kakade et al.*), taking into account the use of storage for water regulation and the discard of water losses in the distribution system, a community of approximately 80 people could be supplied with water.

6. Conclusions

The results of a fog collection experiment in the Andes mountain range of southern Colombia to date are very encouraging and suggest that the implementation of this technology on a large scale is possible. Locations like *Las Torres* and *La Montañuela* showed the highest fog-water collection rates, and they should be considered as potential sites to install operational fog col-

lectors. Las Torres deserves special consideration because in summer, it is the location with the highest fog-water collection yields. June presented the most favourable conditions for fog collection. Conclusive results about which mesh is the most efficient, the 35 % or the 50 % shade coefficient mesh, were not obtained. However, it is recommended for fog collection experiments with SFCs to use the standard 35 % shade coefficient polypropylene mesh, set up in a double layer, to enable direct comparisons to be made between sites in local regions, and between locations around the world. Finally, it was observed that the tested fog collectors can be also effective devices to collect rainwater, mainly in dry seasons. However, there is little research in this area, and more investigation should be done in future experiments, in order to propose modifications to the SFC that increase its efficiency in collecting rainwater.

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7. References

Calvani, S. 2007: La coca, pasado y presente, mitos y realidades. – Bogota

Carter, V., R.S. Schemenauer, P. Osses and *H. Streeter* 2007: The Atacama Desert Fog Collection Project at Falda Verde, Chile. – In: *Biggs, A.* and *P. Cereceda* (eds.): Proceedings of the Fourth International Conference on Fog, Fog Collection and

Dew, Pontificia Universidad Católica de Chile, La Serena (Chile), 22-27 July 2007. – La Serena: 391-394

Cereceda, P., R.S. Schemenauer y *F. Velázquez* 1997: Variación temporal de la niebla en el Tofo-Chungungo, Región de Coquimbo, Chile (1987-1995). – Revista de Geografía Norte Grande **24**: 103-111

Cereceda, P., P. Osses, X. Borojevic, H. Larraín, P. Lázaro y *R.S. Schemenauer* 2000: La Niebla, Agua Potable para Zonas Rurales. – Revista Geográfica de Chile Terra Australis **45**: 143-160

Dingman, S.L. 1994: Physical Hydrology. – New York

Fernandez, D.M. and *G. Ruiz* 2007: Central California Water Collection from Coastal Fog: An Initial Study. – In: *Biggs, A.* and *P. Cereceda* (eds.): Proceedings of the Fourth International Conference on Fog, Fog Collection and Dew, Pontificia Universidad Católica de Chile, La Serena (Chile), 22-27 July 2007. – La Serena: 221-224

GWP (Global Water Partnership) 2000: Agua para el siglo XXI: De la visión a la acción – América del Sur. – Document prepared for presentation at the 2nd World Water Forum, The Hague, March 2000. – Stockholm

Kakade, B., H. Kulkarni, A. Marathe, K. Petare, G. Neelam and *P. Nagargoje* (no year): Integration of Drinking Water Supply-Sanitation and Watershed Development. – WHIRL Project Working Paper **5**. – Online available at: http://www.nri.org/projects/WSS-IWRM/Reports/WHIRL_working_paper_5.pdf

Marzol, M.V., A. Alaeddine, J. Sanchez, and *A. Derhem* 2007: Evaluation of Fog Collection in Ifni, Morocco. In: *Biggs, A.* and *P. Cereceda* (eds.): Proceedings of the Fourth International Conference on Fog, Fog Collection and Dew, Pontificia Universidad Católica de Chile, La Serena (Chile), 22-27 July 2007. – La Serena: 387-390

Marzol, M.V. and *J.L. Sánchez Megía* 2008: Fog Water Harvesting in Ifni, Morocco. An Assessment of Potential and Demand. – DIE ERDE **139** (1-2): 97-124

Mileta, M. 2007: Seven Years of Fog Measurements with SFC in Croatia. – In: *Biggs, A.* and *P. Cereceda* (eds.): Proceedings of the Fourth International Conference on Fog, Fog Collection and Dew, Pontificia Universidad Católica de Chile, La Serena (Chile), 22-27 July 2007. – La Serena: 29-32

- Molina, J.M. y C. Escobar* 2005: La Neblina como Fuente de Agua. Evaluación de su colección en el Sur de los Andes Colombianos Usando Mallas de Polipropileno. – *Avances en Recursos Hidráulicos* **12**: 33-42
- Molina, J.M.* 2007: Spatial and Temporal Variability of Fog Water Collection in a Mountainous Zone of Southern Colombia. – In: *Biggs, A. and P. Cereceda* (eds.): Proceedings of the Fourth International Conference on Fog, Fog Collection and Dew, Pontificia Universidad Católica de Chile, La Serena (Chile), 22-27 July 2007. – La Serena: 101-104
- Prada, S., M. Oliveira, C. Figueira, M.M. de Sequeira and A. Pontes* 2007: Fog Water Collection in Madeira Island (Portugal). – In: *Biggs, A. and P. Cereceda* (eds.): Proceedings of the Fourth International Conference on Fog, Fog Collection and Dew, Pontificia Universidad Católica de Chile, La Serena (Chile), 22-27 July 2007. – La Serena: 277-280
- Schemenauer, R.S. and P. Cereceda* 1994a: Fog Collection's Role in Water Planning for Developing Countries. – *Natural Resources Forum* **18**: 91-100
- Schemenauer, R.S. and P. Cereceda* 1994b: A Proposed Standard Fog Collector for Use in High-elevation Regions. – *Journal of Applied Meteorology* **33** (11): 1313-1322
- Schemenauer, R.S. and P. Cereceda* 1994c: The Role of Wind in Rainwater Catchment and Fog Collection. – *Water International* **19** (2): 70-76
- Schemenauer, R.S. and P.I. Joe* 1989: The Collection Efficiency of a Massive Fog Collector. – *Atmospheric Research* **24**: 53-69
- Tehelen, K.* 2006: Componentes ambientales de una propuesta de pago por servicios ambientales para el manejo de los recursos hídricos en la cuenca del Río Barbas, Quindío, Colombia. – M.Sc. thesis in Environmental Socioeconomy, Center for Tropical Agricultural Research and Education (CATIE), Turrialba, Costa Rica
- Chapagain, A.K. and A.Y. Hoekstra* 2004: Water Footprints of Nations. 1: Main Report. – Value of Water Research Report Series **16**. – UNESCO-IHE. – Delft
- Villegas, L., P. Jimenez, C. Talavera and A. Ortega* 2007: Evaluation of Fog Water Catchment in Atiquipa Lomas (Arequipa, Peru) from 2002 to 2006. – In: *Biggs, A. and P. Cereceda* (eds.): Proceedings of the Fourth International Conference on Fog, Fog Collection and Dew, Pontificia Universidad Católica de Chile, La Serena (Chile), 22-27 July 2007. – La Serena: 225-227
- Summary: Fog Collection Variability in the Andean Mountain Range of Southern Colombia*
- Hydrological droughts occur naturally in some regions of the Colombian Andean watersheds and the associated water scarcity is aggravated by an advancing deforestation of the native highland forests. These events have negative consequences in terms of water supply to rural areas, for both human consumption and agricultural purposes. Low water availability in arid/semiarid regions and water scarcity in surface sources in mountainous zones could be managed partially by means of water from fog collection. This study evaluates the spatial and temporal fog collection variability and analyses the potential use of fog as an alternative source of water supply in an Andean rural region of southern Colombia. The study region has a semiarid climate and the main activities in this zone are agriculture and stockbreeding. Water supply for both human consumption and meat and milk production are highly affected by low water availability, especially during the dry periods of January-March and June-July. Fog collection experiments were carried out, and data collection covered both dry and rainy seasons in the period 2003-2005, with daily data registration of fog collection and precipitation. Twelve Standard Fog Collectors (SFC), built from polypropylene mesh with a vertical collection surface of 1.0 m², were installed in a mountainous zone with an area of approximately 500 ha, ranging from 1,680 to 1,850 m a.s.l. The installation sites of the SFCs were selected based on topographic and fog formation conditions, and Chilean meshes with two shade coefficients, 35 % and 50 %, were tested. In order to assess the spatial fog variability, isolines of fog-water collection rates were estimated using Kriging as the interpolation method. Our results indicate a high potential for the use of fog to meet domestic water requirements in rural areas. Also, the observed collection yields are consistent with experimental results of fog harvest-

ting from other countries in the Andean region. Annual average collection rates amounted to 4.2 l per m² per day for precipitation + fog, and 3.3 l per m² per day for fog only. The most important month for collection was June with 5.3 l per m² per day for rainfall + fog, and 5.0 l per m² per day for fog only in dry days. Finally, it was observed that the tested fog collectors can also be effective devices to collect rainwater, mainly in dry seasons.

Zusammenfassung: Variabilität der Nebelwassersammlung in den südlichen kolumbianischen Anden

In einigen Einzugsbereichen in den kolumbianischen Anden treten regelmäßig hydrologische Dürren auf. Die damit verbundene Wasserknappheit wird durch eine fortschreitende Abholzung der einheimischen Gebirgswälder verschärft. Diese Ereignisse haben negative Folgen für die Wasserversorgung in ländlichen Gebieten, sowohl hinsichtlich des Wasserverbrauchs der Bevölkerung als auch hinsichtlich der Nutzung für landwirtschaftliche Zwecke. Die geringe Verfügbarkeit von Wasser in ariden bzw. semiariden Gebieten und die Knappheit an Oberflächenwasser in Gebirgsregionen könnte teilweise durch Wassergewinnung aus Nebel ausgeglichen werden. Die vorliegende Studie untersucht die räumliche und zeitliche Variabilität von Nebelsammlern und analysiert die mögliche Verwendung von Nebel als einer alternativen Wasserquelle in einer ländlichen Andenregion im Süden Kolumbiens. Das Untersuchungsgebiet weist ein semiarides Klima auf. Die wichtigsten wirtschaftlichen Nutzungen in diesem Gebiet sind Ackerbau und Viehzucht. Die Wasserknappheit stellt Probleme für den menschlichen Bedarf sowie auch für die Produktion von Fleisch und Milch dar, vor allem während der Trockenperioden von Januar bis März und von Juni bis Juli. Für die Untersuchung wurden Nebelsammel-Experimente durchgeführt. Die Datengewinnung umfasste tägliche Aufnahmen von Nebel- und Regendaten, sowohl in der Trocken- als auch in der Regenzeit, im Zeitraum 2003-2005. Zwölf „Standard-Nebelsammler“ (SFCs) mit jeweils einem 1 m² großen Netz aus Polypropylen wurden in einem ungefähr 500 ha großen Bereich des Gebirges, in einer Höhenlage zwischen 1680 und 1850 m ü. NN,

aufgestellt. Die Standorte der Nebelsammler wurden auf der Grundlage der Topographie und der Nebelbildungsbedingungen ausgewählt. Es wurden zwei verschiedene Typen chilenischer Sammelnetze mit Bedeckungskoeffizienten von 35 % bzw. 50 % getestet. Zur Bestimmung der räumlichen Variabilität des Nebels wurden Isolinien der erhobenen Wassersammelmengen gezeichnet, unter Verwendung von Kriging als Interpolationsverfahren. Unsere Ergebnisse zeigen ein hohes Potenzial der Nutzung des Nebels für die Wasserversorgung der Haushalte in den ländlichen Gebieten. Die beobachteten Sammelerträge stehen dabei auch im Einklang mit den experimentellen Ergebnissen hinsichtlich der Nebelernte aus anderen Ländern der Anden-Region. Im Jahresdurchschnitt beliefen sich die Sammelmengen auf 4,2 l pro m² und Tag (Niederschläge + Nebel) und 3,3 l pro m² und Tag (ausschließlich Nebel). Der wichtigste Monat für die Wassergewinnung war der Juni mit 5,3 l pro m² und Tag (Niederschläge + Nebel) und 5,0 l pro m² und Tag (ausschließlich Nebel, an trockenen Tagen). Außerdem wurde festgestellt, dass die getesteten Nebelsammler durchaus auch als Geräte zum Auffangen von Regenwasser geeignet sind, vor allem in der Trockenzeit.

Résumé: La variabilité de la collection de brouillard dans la Cordillère des Andes en Colombie méridionale

Des sécheresses hydrologiques se produisent naturellement dans certaines régions des bassins versants des Andes colombiennes, et le manque d'eau y est aggravé par la progression de la déforestation des forêts naturelles de la haute montagne. Ces événements ont des conséquences négatives en termes d'approvisionnement en eau des zones rurales, tant pour la consommation humaine qu'à des fins agricoles. La faible disponibilité de l'eau dans les zones arides et semi-arides et la rareté de l'eau des sources de surface dans les zones montagneuses pourraient être compensées en partie par l'usage de l'eau provenant de la collection de brouillard. Cette étude évalue la variabilité spatiale et temporelle de la collecte de brouillard et analyse les possibilités d'utilisation du brouillard comme source alternative d'approvisionnement en eau dans une région rurale andine du sud de la Colombie. Le terrain de recherche

présente un climat semi-aride, et les principales activités dans cette zone sont l'agriculture et l'élevage. L'approvisionnement en eau tant pour la consommation humaine que pour la production de lait et de viande est fortement affecté par une faible disponibilité de l'eau, en particulier pendant les périodes sèches allant de janvier à mars et de juin à juillet. Des expériences de collecte de brouillard ont été réalisées, la collecte de données couvrant à la fois des saisons sèches et humides au cours de la période de 2003 à 2005, avec un enregistrement quotidien des données de collecte de brouillard et de précipitations. Douze collecteurs de brouillard standard (SFC) en filet de propylène d'une surface de collection verticale de 1,0 m² chacun ont été installés dans une zone montagneuse d'une superficie d'environ 500 hectares sur une altitude allant de 1680 à 1850 m. Les sites d'installation des SFC ont été choisis en fonction de la topographie et des conditions de formation de brouillard, et deux maillages « chiliens » présentant des coefficients d'ombrage de 35% et de 50% ont été testés. Afin d'évaluer la variabilité spatiale du brouillard, des isolignes de taux de collecte d'eau de brouillard ont été estimées à l'aide de la méthode d'interpolation du krigeage. Nos résultats indiquent le potentiel élevé de l'utilisation du brouillard pour la couverture des besoins domestiques en eau dans les zones rurales. Aussi, les rendements de collecte observés sont compatibles

avec les résultats expérimentaux issus de la collecte de brouillard dans d'autres pays de la région andine. Les moyennes annuelles des taux de collecte s'élevaient respectivement à 4,2 l par m² et jour (précipitation + brouillard) et à 3,3 par m² et jour (brouillard seulement). Juin s'est avéré le mois de collecte prépondérant avec respectivement 5,3 l par m² et jour (précipitation + brouillard) et 5,0 l par m² et jour (brouillard seulement pendant les journées sèches). Enfin, on a observé que les collecteurs de brouillard testés pouvaient aussi servir comme appareils efficaces pour recueillir l'eau de pluie, principalement pendant les saisons sèches.

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