# STATISTICAL AND OPERATIONAL ASSESSMENT OF FOG-WATER HARVESTING UNDER COMMUNITY-BASED MONITORING IN SEMI-ARID NORTHERN CHILE: FIVE-YEAR EVIDENCE FROM PEÑA BLANCA

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**ABSTRACT**

This study evaluates the statistical and operational performance of fog-water harvesting in the Peña Blanca Agricultural Community, Coquimbo Region, semi-arid northern Chile, using community-based monitoring records from 2020 to 2025. Standard Fog Collectors equipped with Raschel 35% double-layer and Kimre meshes were analyzed through paired comparisons, non-parametric seasonal tests, precipitation-based sensitivity analysis, and correlation analyses with monthly precipitation from a reference meteorological station. Kimre consistently outperformed Raschel 35% double-layer mesh under the local operational conditions analyzed, with an average relative advantage of approximately 25% and statistically significant differences in both parametric and non-parametric tests. This advantage persisted after excluding months with precipitation above 20 mm and under dry or negligible-precipitation conditions, where the relative advantage reached 27.4%. Correlation analyses showed no positive association between monthly precipitation and fog-water collection. Fog-water collection also showed marked seasonal variability, with higher values during spring and summer and lower values toward autumn and winter. These findings provide five-year statistical and operational evidence from a functioning community-managed system, highlighting the relevance of mesh selection, seasonal planning, and sustained monitoring for fog-water harvesting under real field conditions.

***Keywords:*** *Atmospheric water; Fog-water harvesting; Standard Fog Collector; Fog-collector mesh performance; Semi-arid coastal environments.*

## 1. INTRODUCTION

Arid and semi-arid coastal regions face increasing challenges in securing reliable water supplies due to climatic variability, strong seasonality of precipitation, and growing pressure on conventional water sources (Qadir et al., 2021). In semi-arid northern Chile, these conditions are particularly relevant in rural and dispersed settlements, where water availability is constrained by both hydroclimatic variability and structural limitations in access to water (Montecinos et al., 2016; Nicolas-Artero & Blanco-Wells, 2025). At the same time, the interaction between the Pacific Ocean, coastal relief, and atmospheric circulation favors recurrent fog occurrence, creating opportunities to explore fog water harvesting as a complementary water source in areas affected by water scarcity (Schemenauer & Cereceda, 1994; Klemm et al., 2012; Montecinos et al., 2018).

Fog water harvesting is commonly described as a passive water-supply technique in which suspended fog droplets are intercepted by vertical mesh collectors and then drained into a storage system (Schemenauer & Cereceda, 1994; Klemm et al., 2012). Standard Fog Collectors (SFCs) have been widely used to quantify fog-water yield and compare collection potential across sites (Schemenauer & Cereceda, 1994).

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Previous research in Chile and other dryland environments has shown that fog collection depends not only on fog occurrence, but also on local meteorological variables, including wind speed and direction, relative humidity, dew point depression, and the design and material properties of the collecting mesh (Klemm et al., 2012; Montecinos et al., 2018; Fernandez et al., 2018). These factors generate high temporal variability in fog-water yield and make long-term field observations essential for understanding the operational behavior of fog harvesting systems.

In Chile, several studies have demonstrated the potential of fog collection in coastal desert and semi-arid environments (Cereceda et al., 1992; Osses et al., 1998; Larraín et al., 2002; Farías et al., 2005). More recent contributions have advanced from field-based monitoring to spatial and climatic modeling approaches, allowing fog-water potential to be estimated at broader territorial scales (Montecinos et al., 2018; Lobos-Roco et al., 2025; Carter et al., 2025). However, despite these advances, long-term operational assessments under community-managed conditions remain relatively limited. This gap is relevant because the performance and continuity of fog harvesting systems depend not only on atmospheric suitability and technical efficiency, but also on maintenance, local monitoring capacity, and the practical conditions under which systems operate over time (Fessehaye et al., 2014; Qadir et al., 2021; Ait el Kadi et al., 2024; Rivera et al., 2026).

The Peña Blanca Agricultural Community, located in the Coquimbo Region of semi-arid northern Chile, provides a relevant case for analyzing fog-water harvesting under real operational conditions. In this territory, fog collection is embedded in a community-managed system where local knowledge, site selection, monitoring practices, and maintenance routines support the continuity of the infrastructure. From a technical perspective, the available five-year monitoring record offers an opportunity to evaluate standardized daily fog-water collection, compare the performance of Raschel 35% double-layer and Kimre meshes under paired field conditions, and assess whether the observed mesh-performance patterns are robust across monthly precipitation conditions.

This study provides a statistical and operational assessment of fog-water harvesting in the Peña Blanca Agricultural Community between 2020 and 2025. Drawing on community-based monitoring records, the article analyzes paired mesh-performance differences, applies precipitation-based sensitivity analysis, evaluates monthly precipitation–collection patterns, and characterizes seasonal variability. In doing so, it provides original site-specific evidence from a functioning community-managed fog harvesting system and contributes to understanding the role of fog harvesting as a strategic complementary water source in semi-arid coastal environments.

## 2. STUDY AREA

The study was conducted in the Peña Blanca Agricultural Community, located in the municipality of Ovalle, Coquimbo Region, semi-arid northern Chile. This territory forms part of a coastal semi-arid environment where the interaction between the Pacific Ocean, coastal relief, and local atmospheric circulation favors the recurrent occurrence of advective fog, supporting the potential use of fog water harvesting as a complementary water source (Klemm et al., 2012; Montecinos et al., 2016; del Río et al., 2018).

The monitoring site is situated in the Cerro Grande Ecological Reserve, a community-owned area where fog harvesting infrastructure has been developed over time. The area represented in **Fig.1** shows marked topographic contrasts, with elevations ranging approximately from 232 to 673 m a.s.l. These relief conditions are relevant because coastal topography can influence fog interception by modifying exposure to marine air masses and low-cloud advection.

The SFC monitoring point is located inside the reserve and is connected to the surrounding territory through local access roads. This setting makes Peña Blanca a relevant case for evaluating fog water harvesting under real operational conditions, since the monitoring system is embedded in a locally managed territory where access, maintenance, and measurement routines contribute to the continuity of the infrastructure.

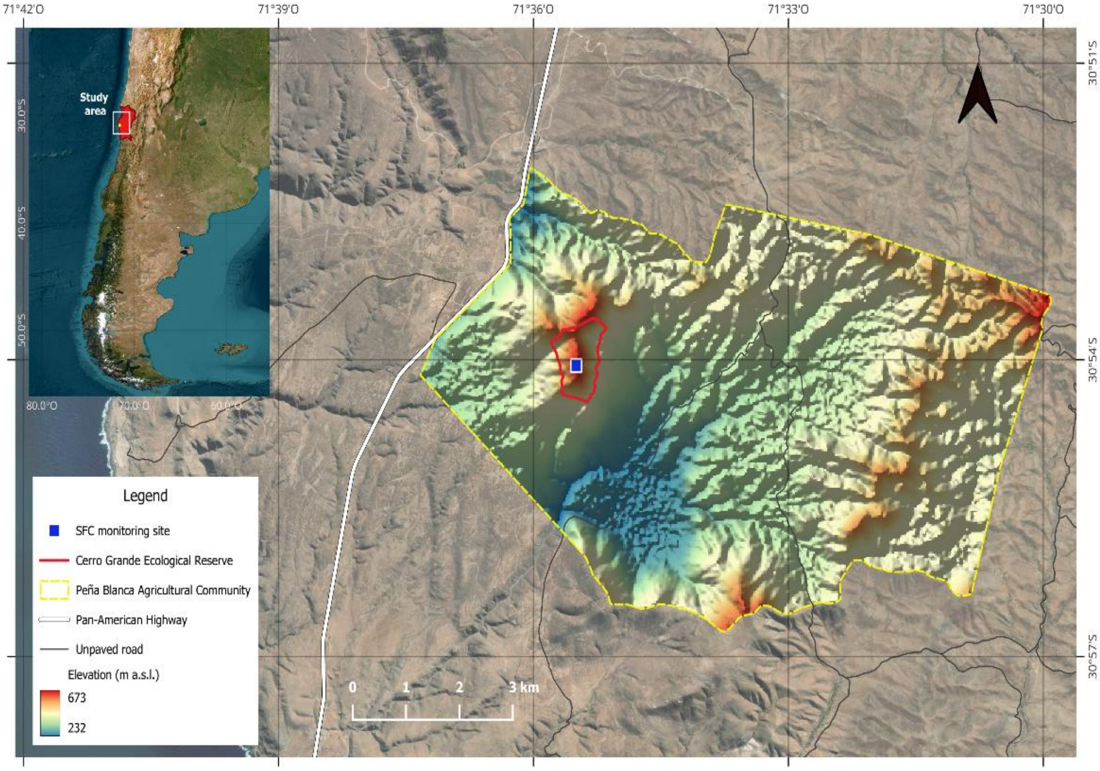


**Fig. 1.** Location of the study area in the Peña Blanca Agricultural Community, Coquimbo Region, semi-arid northern Chile.

## 3. DATA AND METHODS

### 3.1. Fog collectors and mesh materials

Fog-water collection was measured using Standard Fog Collectors, which are widely used to quantify fog-water yield on vertical collecting surfaces and to facilitate comparisons between sites (Schemenauer & Cereceda, 1994). Each SFC had an effective collecting area of 1 m², with the collecting mesh installed approximately 2 m above ground level. A lower gutter directed the collected water into a storage container.

Two mesh materials were monitored: Raschel 35% and Kimre. The collectors were installed in the same monitoring sector, approximately two meters apart, allowing their performance to be compared under similar local exposure and atmospheric conditions. The Raschel 35% collector used a double layer of 35% shade-coefficient Raschel mesh, consistent with the standard SFC configuration proposed by Schemenauer and Cereceda (1994). Raschel 35% is a Raschel-woven mesh commonly used in fog collection systems. It consists of high-density polyethylene filaments with UV protection and a triangular weave; the 35% value refers to the nominal shade coefficient of the mesh, which describes its degree of shading or obstruction.

This parameter is relevant because mesh structure and openness influence airflow through the collector, droplet interception, and drainage behavior (Schemenauer & Cereceda, 1994; Rivera, 2011; Fernandez et al., 2018). Kimre, by contrast, is a structured three-dimensional mesh made of interlocking thermoplastic monofilaments. Its volumetric configuration provides a larger contact surface than a flat mesh and was included to evaluate whether differences in mesh structure affect standardized operational collector yield under the same field conditions.

### 3.2. Operational monitoring and data standardization

Fog-water collection was evaluated from operational monitoring records covering the period 2020–2025. Field readings of accumulated water volume were carried out approximately every 10 days, depending on site access and operational conditions.

The monitoring process was supported by a local community operator, who conducted field measurements and periodic inspection of the collectors. To ensure temporal comparability, accumulated volumes measured between field visits were converted into standardized daily fog-water collection, expressed in $L \cdot m^{-2} \cdot day^{-1}$, following the standard area- and time-normalized reporting convention used in fog-collector studies (Schemenauer & Cereceda, 1994; Klemm et al., 2012) (Eq. 1).

$$q_i = \frac{V_i}{A \cdot \Delta t_i} \quad (1)$$

where $q_i$ is the daily fog-water collection for period $i$ ($L \cdot m^{-2} \cdot day^{-1}$), $V_i$ is the accumulated volume between two consecutive readings (L), $A$ is the effective collector area (1 $m^2$), and $\Delta t_i$ is the number of days between consecutive readings.

### 3.3. Precipitation data

Monthly accumulated precipitation data were obtained from the nearest available CEAZAMET meteorological station, "Peña Blanca", operated by the Centro de Estudios Avanzados en Zonas Áridas (CEAZA, 2019). The station is located approximately 7 km from the SFC monitoring site and was used as a monthly precipitation reference for the study area. Precipitation was expressed as monthly totals in millimeters (mm) and used as auxiliary information for the precipitation-based sensitivity analysis and for evaluating monthly precipitation–collection patterns. Monthly precipitation records were paired by year and month with the corresponding monthly mean daily fog-water collection values.

### 3.4. Statistical analysis

Statistical analysis focused on mesh-performance differences, precipitation-based sensitivity analysis, the relationship between monthly precipitation and fog-water collection, and seasonal variability. The main comparative analysis was based on simultaneous observations for Raschel 35% and Kimre, in order to maintain a paired design and control for shared temporal variability. Standardized daily fog-water collection was aggregated by year and month to support precipitation-related and seasonal analyses.

The comparison between Raschel 35% and Kimre was performed using simultaneous observations available for both meshes. For each paired observation, the absolute difference was calculated as:

$$D_i = q_{K,i} - q_{R,i} \quad (2)$$

where $D_i$ is the paired difference for observation $i$, $q_{K,i}$ is the Kimre standardized daily fog-water collection, and $q_{R,i}$ is the Raschel 35% standardized daily fog-water collection.

The relative performance ratio was calculated as:

$$G_i = \frac{q_{K,i}}{q_{R,i}} \quad (3)$$

where $G_i$ represents the relative performance ratio of Kimre compared with Raschel 35% for each paired observation.

The hypothesis that Kimre yielded higher standardized daily fog-water collection than Raschel 35% was evaluated using a paired Student's t-test. As a non-parametric alternative, the Wilcoxon signed-rank test was also applied to assess whether the paired differences were consistently positive. In addition to statistical significance, effect size was reported using Cohen's $d$ (Eq. 4) for paired samples (Cohen, 1988).

$$d = \frac{\bar{D}}{s_D} \tag{4}$$

where $\bar{D}$ is the mean paired difference and $s_D$ is the standard deviation of the paired differences. This allowed the practical magnitude of the difference between mesh materials to be interpreted beyond the *p*-value.

To assess whether mesh-performance differences were sensitive to monthly precipitation conditions, a precipitation-based sensitivity analysis was conducted using precipitation records from the CEAZAMET Peña Blanca station. The paired Kimre–Raschel comparison was repeated under three precipitation-screening scenarios: all paired months with available precipitation data, after excluding months with precipitation above 20 mm, and considering only dry or negligible-precipitation months with precipitation equal to or below 5 mm. These thresholds were used to screen records according to monthly precipitation conditions, distinguishing months with higher precipitation from months with low or minimal precipitation. For each scenario, mean Raschel and Kimre fog-water collection rates, mean paired differences, relative advantage, paired t-tests, Wilcoxon signed-rank tests, and Cohen's *d* were calculated.

For the relationship between monthly precipitation and standardized daily fog-water collection, monthly accumulated precipitation totals were paired by year and month with the corresponding monthly mean daily fog-water collection. Pearson's correlation coefficient (Eq. 5) was used to evaluate the linear association between both variables:

$$r = \frac{\sum_{i=1}^{n}(P_i - \bar{P})(q_i - \bar{q})}{\sqrt{\sum_{i=1}^{n}(P_i - \bar{P})^2}\sqrt{\sum_{i=1}^{n}(q_i - \bar{q})^2}} \tag{5}$$

where $P_i$ is monthly precipitation, $q_i$ is monthly mean daily fog-water collection, and $\bar{P}$ and $\bar{q}$ are their respective means.

Spearman's rank correlation coefficient (Eq. 6) was also calculated as a non-parametric measure of monotonic association, appropriate when the relationship between variables may not be linear or when the data do not meet normality assumptions (Hollander et al., 2013):

$$\rho = \frac{\sum_{i=1}^{n}(R(P_i) - \overline{R(P)})(R(q_i) - \overline{R(q)})}{\sqrt{\sum_{i=1}^{n}(R(P_i) - \overline{R(P)})^2}\sqrt{\sum_{i=1}^{n}(R(q_i) - R(\bar{q})^2}} \tag{6}$$

where $R(P_i)$ and $R(q_i)$ are the ranks of monthly precipitation and monthly mean daily fog-water collection, respectively, and the overbars indicate their mean ranks.

In addition, monthly mean daily fog-water collection was explored across precipitation ranges of 0–5 mm, 5–20 mm, and >20 mm to identify whether collection rates varied systematically under different monthly precipitation conditions.

Seasonal variability was analyzed by calendar month and by austral seasons: summer (December–February), autumn (March–May), winter (June–August), and spring (September–November). For the seasonal analysis, monthly mean daily fog-water collection was calculated by aggregating the operational records by year and month. Accumulated volumes assigned to each month were summed and divided by the number of days in the corresponding month, producing monthly values expressed in $L \cdot m^{-2} \cdot day^{-1}$. These monthly values were used to compare seasonal behavior among months and seasons. Seasonal differences were tested separately for each mesh using the Kruskal–Wallis test, given that fog-water collection records may show asymmetric distributions, heteroscedasticity, and unequal data availability among seasonal groups.

For this reason, a non-parametric test that does not require the assumption of normality was preferred (Kruskal & Wallis, 1952). The Kruskal–Wallis statistic was expressed as:

$$H = \frac{12}{N(N+1)} \sum_{j=1}^{k} \frac{R_j^2}{n_j} - 3(N+1) \quad (7)$$

where $N$ is the total number of observations, $k$ is the number of seasonal groups, $R_j$ is the sum of ranks for group $j$, and $n_j$ is the number of observations in group $j$.

The main paired mesh comparison included all simultaneous Kimre–Raschel observations, whereas precipitation-based analyses were restricted to paired observations with available monthly precipitation records. All analyses were conducted using complete cases for the variables required in each specific test, and statistical significance was assessed at $\alpha = 0.05$.

## 4. RESULTS AND DISCUSSIONS

### 4.1. Mesh performance and paired comparison

Considering all simultaneous observations available for both meshes, Kimre showed a higher standardized daily fog-water collection than Raschel 35% double-layer mesh (**Table 1**). Raschel 35% recorded a mean value of 6.82 $L \cdot m^{-2} \cdot day^{-1}$, while Kimre reached 8.51 $L \cdot m^{-2} \cdot day^{-1}$. The mean paired difference was 1.69 $L \cdot m^{-2} \cdot day^{-1}$ in favor of Kimre, corresponding to an average relative advantage of 24.8%. The effect size was $d = 0.75$, indicating a moderate to relevant difference between mesh materials.

The hypothesis tests confirmed this difference. The paired *t*-test showed statistically significant differences between meshes, with $t = 6.07$ and $p = 3.70 \times 10^{-8}$ for the one-tailed test. The Wilcoxon signed-rank test produced consistent results, with $W = 1860$ and $p = 7.19 \times 10^{-7}$. These results indicate that Kimre performed significantly better than Raschel 35% double-layer mesh under the operational conditions analyzed.

**Table 1.**

**Paired comparison of standardized daily fog-water collection ($L \cdot m^{-2} \cdot day^{-1}$) between Raschel 35% double-layer and Kimre meshes during 2020–2025.**

| Descriptive statistics | | | | |
|---|---|---|---|---|
| **Paired monthly observations *n*** | **Mean Raschel 35% collection** | **Mean Kimre collection** | **Mean difference Kimre – Raschel** | **Cohen's *d*** |
| 66 | 6.82 | 8.51 | 1.69 | 0.75 |
| **Hypothesis tests** | | | | |
| **Test** | | **Statistic** | | ***p*-values** |
| **Paired t-test** | | $t = 6.07$ | | $3.70 \times 10^{-8}$ |
| **Wilcoxon signed-rank test** | | $W = 1860$ | | $7.19 \times 10^{-7}$ |
| ***Note:*** *Collection values and mean differences are expressed in $L \cdot m^{-2} \cdot day^{-1}$, p-values correspond to one-tailed tests for the hypothesis Kimre > Raschel.* | | | | |

The paired pattern is further illustrated in **Fig. 2**, where simultaneous Raschel 35% double-layer and Kimre observations are compared against the 1:1 line. Points above this line indicate higher standardized daily fog-water collection for Kimre, while points below it indicate higher values for Raschel 35% double-layer mesh. Most observations are located above the line, showing that the higher mean value of Kimre reflects a recurrent pattern across paired measurements rather than a few isolated cases.

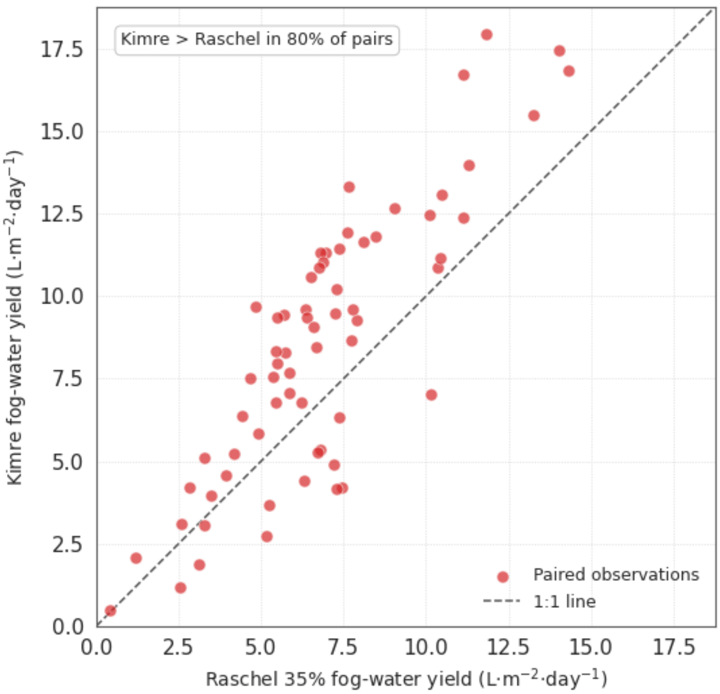


**Fig. 2.** Paired comparison of standardized daily fog-water collection between Raschel 35% double-layer and Kimre meshes during simultaneous observations.

The higher standardized daily fog-water collection observed for Kimre shows that mesh material can substantially influence collector performance under local operational conditions. In Peña Blanca, the paired design allowed both meshes to be compared during the same monitoring periods and in the same sector, reducing the influence of temporal variability in fog occurrence and minimizing differences in local exposure conditions.

This result is consistent with previous studies showing that fog-water collection depends not only on fog occurrence, but also on collector design and mesh properties. The Standard Fog Collector has traditionally used Raschel-type mesh because of its availability, low cost, and usefulness for comparisons among sites (Schemenauer & Cereceda, 1994; Klemm et al., 2012). However, collection efficiency can vary according to mesh geometry, filament arrangement, aerodynamic collection efficiency, droplet interception, and drainage behavior (Rivera, 2011; Fernandez et al., 2018).

From an applied perspective, the contrast between meshes has implications for the design and operation of fog harvesting systems in semi-arid coastal environments. Where water availability is limited, sustained increase in fog-water collection may improve the contribution of fog harvesting without necessarily increasing the number of collectors. However, material selection should not be based only on collection rates. Durability, cost, local availability, maintenance requirements, and long-term operational feasibility should also be considered, particularly in community-managed systems where technical performance must be compatible with local capacities and maintenance routines (Rivera, 2011; Fernandez et al., 2018).

### 4.2. Precipitation-based sensitivity analysis and monthly precipitation–collection patterns

The precipitation-screening analysis showed that the higher performance of Kimre persisted across all evaluated scenarios (**Table 2**). Monthly precipitation during the monitoring period was generally low and episodic within the paired dataset. Among the 63 paired monthly observations with available precipitation data, 46 months recorded 0–5 mm, six months recorded 5–20 mm, and eleven months exceeded 20 mm.

After excluding these eleven higher-precipitation months, 52 paired observations remained for the sensitivity analysis. This distribution is consistent with the broader semi-arid coastal context of northern Chile, where fog harvesting has been studied as a complementary water source in areas with limited conventional freshwater availability (Garreaud et al., 2008; del Río et al., 2018; Lobos-Roco et al., 2025).

Results obtained from the 63 paired months with available monthly precipitation data were very similar to those from the full paired mesh dataset: Raschel 35% double-layer mesh recorded a mean value of 6.88 $L·m^{-2}·day^{-1}$, while Kimre reached 8.56 $L·m^{-2}·day^{-1}$. The mean paired difference was 1.68 $L·m^{-2}·day^{-1}$ in favor of Kimre, corresponding to a relative advantage of 24.4%.

After excluding months with precipitation above 20 mm, 52 paired observations remained. In this subset, Kimre continued to show higher standardized daily fog-water collection than Raschel, with mean values of 8.98 and 7.18 $L·m^{-2}·day^{-1}$, respectively. The mean paired difference remained positive at 1.80 $L·m^{-2}·day^{-1}$, corresponding to a relative advantage of 25.0%. Under dry or negligible-precipitation conditions ($P \leq 5$ mm), the difference was also maintained, reaching 2.00 $L·m^{-2}·day^{-1}$, with Kimre averaging 9.29 $L·m^{-2}·day^{-1}$ compared with 7.29 $L·m^{-2}·day^{-1}$ for Raschel, corresponding to a relative advantage of 27.4%.

Across all precipitation-screening scenarios, the paired t-tests and Wilcoxon signed-rank tests remained statistically significant. The Kimre advantage was maintained after excluding the eleven months with precipitation above 20 mm and under dry or negligible-precipitation conditions. This consistency supports the robustness of the paired mesh comparison under the operational monitoring conditions analyzed.

**Table 2.**
**Sensitivity analysis of Kimre–Raschel 35% double-layer performance differences under monthly precipitation-screening scenarios.**

| Precipitation-screening scenario | *n* | Mean Raschel 35% | Mean Kimre | Mean difference Kimre–Raschel | Relative advantage (%) | Cohen's *d* | Paired *t*-test *p* | Wilcoxon *p* |
|---|---|---|---|---|---|---|---|---|
| **All paired months with precipitation data** | 63 | 6.88 | 8.56 | 1.68 | 24.4 | 0.73 | $1.38×10^{-7}$ | $1.91×10^{-6}$ |
| **Excluding months with P > 20 mm** | 52 | 7.18 | 8.98 | 1.80 | 25.0 | 0.78 | $3.96×10^{-7}$ | $5.45×10^{-6}$ |
| **Dry/negligible-precipitation months, P ≤ 5 mm** | 46 | 7.29 | 9.29 | 2.00 | 27.4 | 0.92 | $7.46×10^{-8}$ | $4.34×10^{-7}$ |

***Note:*** *Collection values and mean differences are expressed in $L·m^{-2}·day^{-1}$. P refers to monthly precipitation recorded at the CEAZAMET Peña Blanca station. p-values correspond to one-tailed paired tests for the hypothesis Kimre > Raschel.*

To complement the precipitation-based sensitivity analysis, the association between monthly precipitation recorded at the CEAZAMET Peña Blanca station and monthly mean daily fog-water collection was evaluated. The association was weak and negative for both meshes: Pearson's correlation coefficient was r = −0.180 for Raschel 35% double-layer mesh and r = −0.187 for Kimre, suggesting the absence of a positive linear relationship between monthly precipitation and fog-water collection (**Fig. 3a**). These correlations were not statistically significant for either mesh, with $p$ = 0.158 for Raschel 35% and $p$ = 0.143 for Kimre.

Spearman's rank correlations were also negative. For Raschel 35%, Spearman's correlation was ρ = −0.261 with $p$ = 0.039, while for Kimre it was ρ = −0.357 with $p$ = 0.004. These results indicate that, at the monthly scale, higher precipitation values recorded at the reference station did not correspond to higher fog-water collection. Rather, the ranked data suggest a weak to moderate negative monotonic association, particularly for Kimre.

The boxplots show the distribution of monthly mean daily fog-water collection for Raschel 35% and Kimre after grouping months into three precipitation ranges: 0–5 mm, 5–20 mm, and >20 mm.

The overlap between distributions and the similarity of the medians suggest that months with higher precipitation did not show, on average, a systematic increase in fog-water collection compared with drier months (**Fig. 3b**). This pattern is consistent with the weak Pearson correlations and the negative Spearman associations observed.

The sensitivity analysis, correlation results, and precipitation-range comparison indicate that monthly precipitation records are useful for contextualizing the monitoring series, but the observed Kimre–Raschel performance difference was robust across the evaluated precipitation subsets. This supports the use of fog-specific monitoring to assess collector performance in semi-arid coastal environments as a complementary water source.

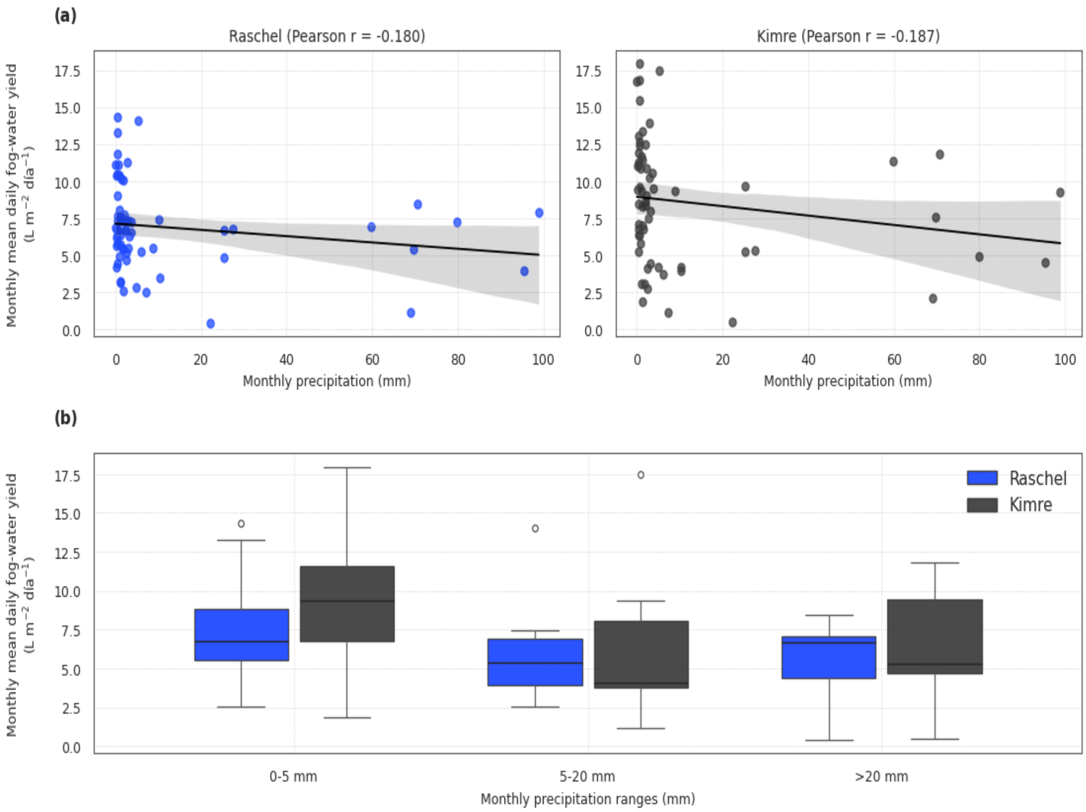


**Fig. 3.** Relationship between monthly precipitation and monthly mean daily fog-water collection ($L \cdot m^{-2} \cdot day^{-1}$) for Raschel 35% double-layer and Kimre meshes during 2020–2025: **(a)** scatterplots with linear trends; **(b)** boxplots of fog-water collection by monthly precipitation ranges.

### 4.3. Seasonal variability of fog-water collection

Fog-water collection showed a marked seasonal pattern in both meshes (**Fig. 4**). For Raschel 35% double-layer mesh, seasonal means were higher in spring (8.64 ± 3.31 $L \cdot m^{-2} \cdot day^{-1}$) and summer (7.62 ± 2.62 $L \cdot m^{-2} \cdot day^{-1}$), and lower in autumn (5.90 ± 2.70 $L \cdot m^{-2} \cdot day^{-1}$) and winter (5.64 ± 1.94 $L \cdot m^{-2} \cdot day^{-1}$). Kimre showed a similar seasonal behavior, with higher values in spring (11.36 ± 3.89 $L \cdot m^{-2} \cdot day^{-1}$) and summer (10.43 ± 3.90 $L \cdot m^{-2} \cdot day^{-1}$), and lower values in autumn (6.40 ± 3.63 $L \cdot m^{-2} \cdot day^{-1}$) and winter (6.66 ± 2.98 $L \cdot m^{-2} \cdot day^{-1}$).

Seasonal differences were statistically significant for both meshes according to the Kruskal–Wallis test. For Raschel 35%, the test yielded $H = 10.34$ and $p = 0.0159$, while for Kimre it yielded $H = 17.98$ and $p = 0.0004$. These results indicate that fog-water collection varied significantly throughout the year, with the highest values generally observed during spring and summer and the lowest values toward late autumn and early winter.

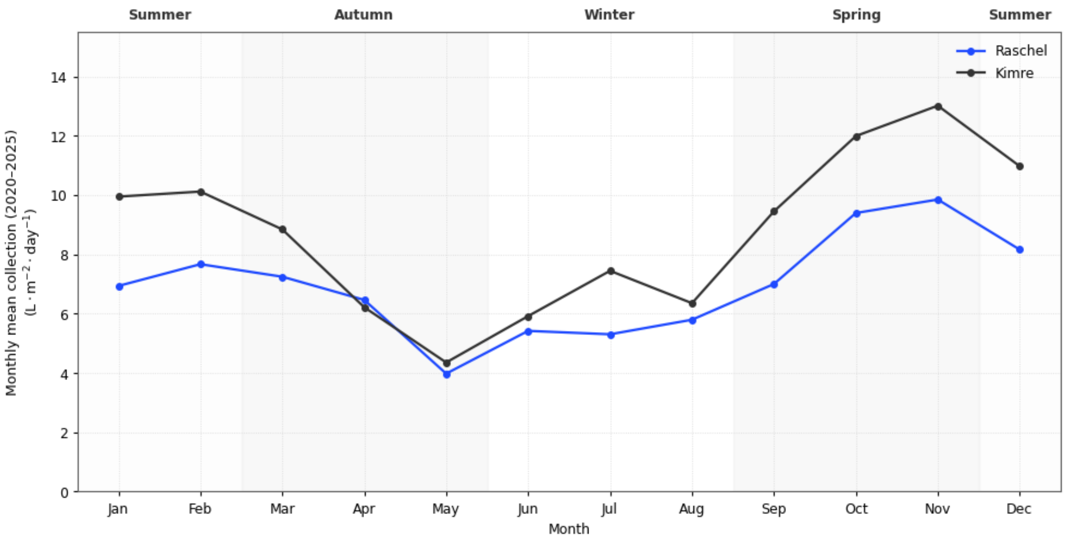


**Fig. 4.** Monthly mean daily fog-water collection for Raschel 35% double-layer and Kimre meshes during 2020–2025. Austral seasons are indicated above the monthly axis.

The seasonal pattern observed in Peña Blanca is consistent with the high temporal variability of coastal fog systems in semi-arid Chile and with the seasonality documented in Standard Fog Collector measurements (Klemm et al., 2012; Montecinos et al., 2018). In this case, the five-year operational record provides site-specific evidence for a community-managed fog harvesting system, where seasonal differences are directly relevant for water-use planning, storage capacity, maintenance schedules, and operational management during the months of higher production (Klemm et al., 2012; Carter et al., 2025).

This seasonal contrast indicates that fog harvesting does not provide a constant supply throughout the year, but rather a contribution concentrated in specific temporal windows. Therefore, the seasonal cycle of fog-water collection should be considered explicitly when evaluating the role of fog harvesting as a complementary water source in semi-arid coastal environments.

### 4.4. Fog harvesting as a complementary water source

The Peña Blanca case shows that fog harvesting can constitute a strategic complementary water source in semi-arid coastal environments, particularly where conventional freshwater availability is limited and local communities require diversified water practices. Its contribution should not be understood only in terms of isolated collection volumes, but also in relation to its capacity to support local water management when the system is continuously monitored, maintained, and integrated into community-based operational routines (Fessehaye et al., 2014; Qadir et al., 2021; Ait el Kadi et al., 2024).

A central contribution of this study is that it provides original site-specific evidence from a locally sustained operational monitoring experience in Peña Blanca. This operational perspective is relevant because long-term records from functioning community-managed fog harvesting systems are necessary to understand not only collection rates, but also the practical conditions that shape their continuity, maintenance, and performance over time.

Additionally, these findings have practical implications for the design and operation of fog harvesting systems in semi-arid coastal environments. The higher performance observed for Kimre suggests that mesh selection can improve fog-water collection under local operational conditions. However, in community-managed systems, material selection should not be based only on collection rates, but also on maintenance requirements, durability, local availability, storage capacity, and community management capacity, particularly in long-term operational systems (Fessehaye et al., 2014; Qadir et al., 2021; Ait el Kadi et al., 2024).

Likewise, the marked seasonal variability observed in Peña Blanca indicates that fog harvesting requires planning around periods of higher and lower production, rather than assuming a constant supply throughout the year (Klemm et al., 2012; Montecinos et al., 2018; Carter et al., 2025). In this sense, fog harvesting in Peña Blanca should be understood as both a technical and operational practice. Its potential contribution is shaped by the interaction between measured fog-water collection, mesh performance, storage possibilities, maintenance routines, local monitoring capacity, and community organization. This interpretation is consistent with recent work on Peña Blanca that highlights the role of collective action and territorial organization in local water practices (Di Tullio & Zannini, 2025).

## 5. CONCLUSIONS

This study evaluated the operational performance of fog-water harvesting in the Peña Blanca Agricultural Community, semi-arid northern Chile, using five years of locally sustained monitoring records from 2020 to 2025. The results provide original site-specific evidence from a functioning community-managed fog harvesting system and show that standardized daily fog-water collection varies according to mesh configuration and seasonal conditions under real operational monitoring.

The paired comparison showed that Kimre consistently outperformed Raschel 35% double-layer mesh under the local operational conditions analyzed. This difference was statistically significant in both parametric and non-parametric tests and represented an average relative advantage of approximately 25% in favor of Kimre. The precipitation-based sensitivity analysis reinforced this pattern: after excluding months with precipitation above 20 mm, Kimre maintained a relative advantage of 25.0%, and the advantage also persisted under dry or negligible-precipitation conditions, reaching 27.4%. In addition, the correlation analyses showed no positive association between monthly precipitation and fog-water collection. These findings indicate that the observed difference between meshes was robust across the evaluated monthly precipitation subsets and support the relevance of mesh selection for improving collector performance under community-based operational conditions.

Fog-water collection in Peña Blanca also showed marked seasonal variability, with higher values during spring and summer and lower values toward autumn and winter. This seasonal pattern indicates that fog harvesting should not be understood as a uniform supply throughout the year, but rather as a complementary contribution concentrated in specific production windows. Therefore, storage capacity, maintenance schedules, water-use planning, and local management routines are essential for sustaining its contribution over time.

The Peña Blanca case demonstrates that fog harvesting can constitute a strategic complementary water source in semi-arid coastal environments when its technical performance is evaluated together with long-term monitoring, seasonal variability, and local operational conditions. The study highlights that mesh selection, sustained data collection, seasonal planning, and local institutional and community capacity are key dimensions for improving the design, assessment, and continuity of fog harvesting systems under real field conditions.


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