Preservation and Monitoring of the Cloud Forest in Coatepec: A Community Strategy for Cloud Forest Conservation

FIDECOAGUA

Coatepec, Mexico
2025

INTRODUCTION

FIDECOAGUA is a Decentralized Public Organization with the legal status of a trust, established in 2002 by the Honorable Municipality of Coatepec, in collaboration with the Municipal Water and Sanitation Commission of Coatepec (CMAS) and the National Forestry Commission (CONAFOR). Its objective is to concentrate resources from the public and private sectors to implement a Payment for Environmental Services (PES) program for the protection of the Montane

Cloud Forest (MCF). This forest not only provides essential environmental resources that supply over 90,000 people in surrounding areas—such as potable water, timber, and medicinal plants—but also promotes awareness actions that address current challenges such as population growth, resource exploitation, and deforestation, which have caused considerable losses of these ecosystem services and led to environmental degradation.

The FIDECOAGUA community includes 177 forest owners from twelve localities in the mountainous region of Coatepec, including Ingenio del Rosario, Carrizal, Mesa de Laurel, Tierra Grande, Coatepec Viejo, Cuesta del Pino, Loma Alta, Tapachapan, Cinco Palos, Colonia Cuauhtémoc, Zimpizahua, and Zoncuantla. These landowners receive $1,000 MXN (approximately $58 USD) per hectare annually, which has enabled the protection of 1,406.83 hectares of Montane Cloud Forest. The mission of the FIDECOAGUA community is to support the well-being of forest owners by strengthening conservation practices to continue obtaining both direct and indirect benefits from the MCF, including the hydrological services of the micro-watersheds of Coatepec that supply water to the region.

To strengthen its positioning with decision-makers, FIDECOAGUA has established strategic alliances with governmental entities (Municipality of Coatepec, SEDEMA, CONAFOR, CMAS), academic institutions (Universidad Veracruzana, Instituto Tecnológico Superior de Perote), and civil society organizations (PRONATURA Veracruz A.C., GLOBAL WATER WATCH A.C.). These collaborations have facilitated dissemination, conservation, and reforestation activities, including the decree that designated La Cortadura as a Protected Natural Area.

Additionally, support from private companies such as Coca-Cola FEMSA, Nestlé S.A. de C.V., and ZUCARMEX has allowed FIDECOAGUA to maintain a stable budget for more than ten years, ensuring payments to forest owners for their conservation efforts.

In collaboration with AGU Thriving Earth Exchange, precise hydrological data were collected on water quality within the montane cloud forest and pine-oak forest, integrated into the conservation program. This demonstrated the forest's key role in providing environmental services and encouraged further private and community investment in Payment for Environmental Services schemes.

Data collection was carried out between December 2023 and August 2025 at eight sites (AL1, AL2, ARA1, ARA2, EU1, EU2, MAC1, LAJ) located in mid- and high-altitude areas (Las Lajas, Colonia Cuauhtémoc, Loma Alta, and Ingenio del Rosario). During this period, various environmental parameters were evaluated, including flow, conductivity, dissolved solids, UV radiation, total organic carbon, chemical oxygen demand (COD), and Escherichia coli presence in areas with agricultural and livestock activities.

Additionally, a macroinvertebrate taxa index was developed, classifying observed species into three groups:

- **Group 1:** Water beetle, Whirligig beetle, Snail, Mayfly, Stonefly, Caddisfly

- **Group 2:** Amphipod, Freshwater prawn (Acamaya), Asian clam, Water louse, Dragonfly A, Dragonfly Z, Dobsonfly, Blackfly, Crane fly, Filter-feeding caddisfly

- **Group 3:** Pulmonate snail, Midge (Chironomid), Aquatic worm, Leech

This approach allowed characterization of the diversity and abundance of macroinvertebrates in different aquatic ecosystems, providing key information on water quality and environmental health of the Montane Cloud Forest micro-watersheds in Coatepec.

Description of Monitored Sites

Period: December 2023 – August 2025

Active monitoring is currently carried out in four communities in the municipality of Coatepec, selected for their strategic locations at different altitudinal ranges: Las Palomas, Ingenio del Rosario (2,800 masl), Loma Alta (1,400–2,140 masl), Colonia Cuauhtémoc (1,200 masl), and Las Lajas, Consolapan (1,200 masl). Each of these communities has unique social, economic, and environmental characteristics that determine their priorities, organizational structure, and approach to socio-environmental challenges.

Las Palomas, Ingenio del Rosario (2,800 masl)

The highland areas on the slopes of Cofre de Perote, particularly in communities such as Las Palomas and Ingenio del Rosario, currently experience accelerated environmental degradation. To address this, a strategic monitoring system has been established to generate reliable information for designing and implementing mitigation actions aimed at conserving and restoring local ecosystems.

Monitoring activities are conducted at two sites, ARA1 and ARA2, located along the El Caracol tributary, which supplies water to nearby communities. The main difference between the sites is location: ARA1 is upstream, and ARA2 is downstream within the same property. The Las Palomas community is composed of ejidatarios and small private landowners, whose lands predominantly maintain pine-oak forest cover.

Currently, El Caracol River shows impacts from irregular drainage located between the two monitoring points. This issue prompted targeted sampling for E. coli to evaluate water quality and generate technical information to support proper management of the region's water bodies, within the framework of preventive and corrective measures against environmental degradation. Other variables measured at these sites were also included to generate correlations across all monitoring activities.

Loma Alta (1,400–2,140 masl)

Community water quality monitoring is conducted in two zones: upper and mid-altitude. In the upper zone (2,140 masl), within a property enrolled in the PES program, the sites AL1 (upstream) and AL2 (downstream) are located. This area maintains intact montane cloud forest cover, without productive or livestock activities. The objective of this monitoring is to generate technical evidence on the ecosystem benefits provided by forest conservation, particularly in hydrological regulation and water quality maintenance.

In the lower zone (1,400 masl) along the same river, two additional sites are monitored: EU1 (upstream) and EU2 (downstream). This area combines remnants of montane cloud forest with shade-grown coffee agroforestry systems, where no agrochemicals are used due to organic farming practices. The monitoring aims to understand hydrological dynamics and water quality in sustainable production contexts, evaluating how these practices coexist with the ecosystem and contribute to the conservation of environmental services.

Colonia Cuauhtémoc (1,200 masl) and Las Lajas, Consolapan (1,200 masl)

At lower altitudes (1,200 masl), two strategic monitoring sites were established: MAC1 (upstream in Colonia Cuauhtémoc) and LAJ (Las Lajas, Consolapan). The sites are approximately one kilometer apart and are embedded in a mosaic of montane cloud forest cover combined with potato cultivation areas. Unregulated agrochemical use has been identified in this zone, raising concerns among residents due to potential impacts on human health and aquatic ecosystems. Monitoring at these sites aims to obtain technical information to understand water dynamics and the influence of agricultural practices on water quality, supporting improved agricultural management and community/regional water planning.

RESULTS AND ANALYSIS

Water quality was evaluated at eight sites through physicochemical, bacteriological, and biomonitoring analyses, considering variables such as COD, TOC, UV275, TDS, EC, biological indicators, E. coli counts, total coliforms, and number of taxa.

Overall, water quality in the monitored region is favorable; however, vulnerable sites were identified that require ongoing monitoring and the implementation of targeted measures, especially for discharge control and integrated watershed management.

BIOMONITORING

Biomonitoring was conducted by counting macroinvertebrate taxa present at the eight previously mentioned sites. Results show notable differences in taxa numbers and accumulated indices between sites.

Specifically, AL1 and AL2 recorded the highest values for both indicators over time, demonstrating better water quality compared to other sites. Conversely, the other sites had lower values and no significant differences between them, suggesting relatively lower water quality.

These findings highlight the utility of biomonitoring as an ecological indicator, reflecting overall environmental conditions and the health of aquatic ecosystems at different sampling points.
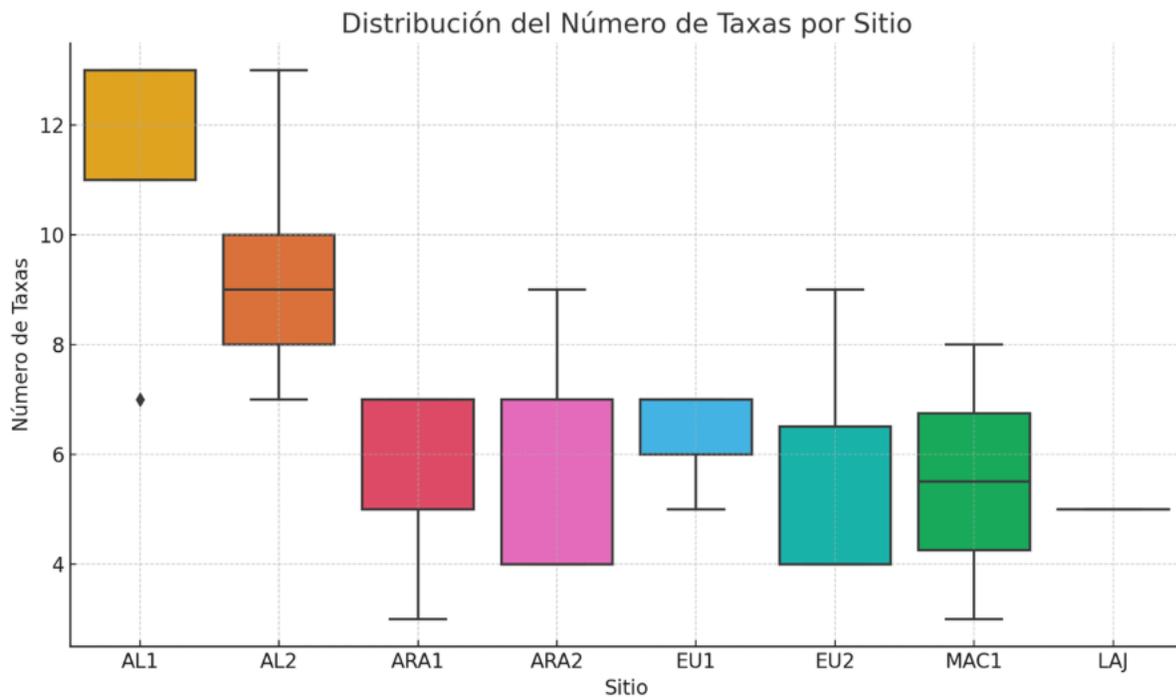

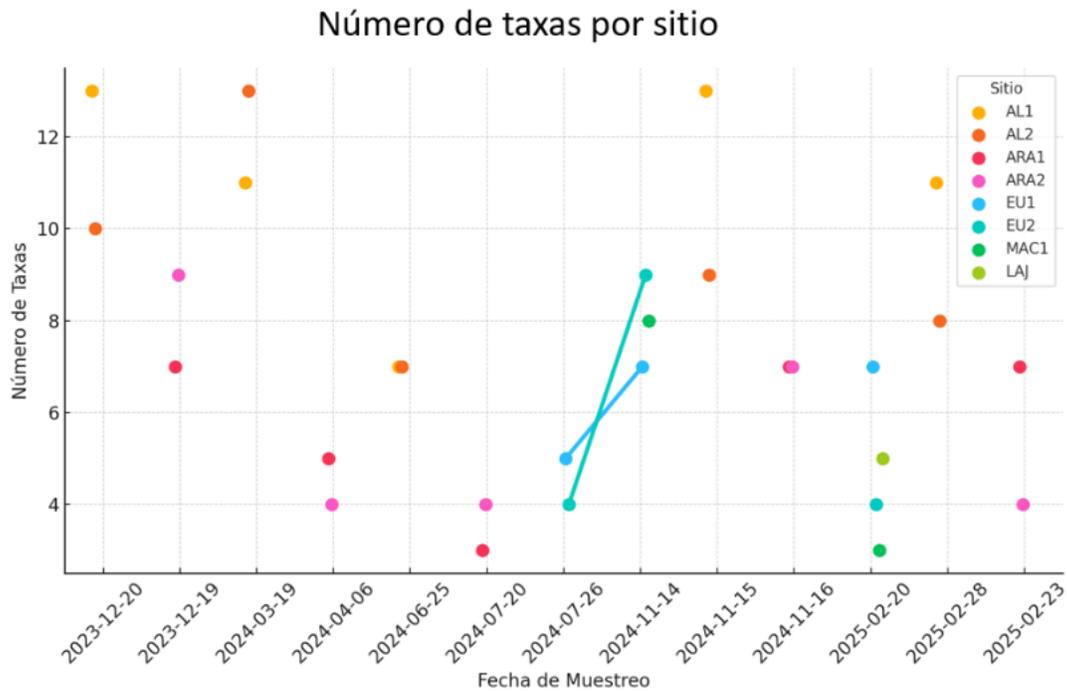Figure 1: Distribution of the number of macroinvertebrate taxa per site.

Figure 2: Number of taxa recorded per site on different sampling dates. The figure shows variations in macroinvertebrate richness among sampling sites over time.

According to field observations, sites AL1 and AL2 have montane cloud forest cover and no anthropogenic activities. These results indicate that human disturbances negatively affect the composition and diversity of aquatic macroinvertebrates. In general, as the degree of anthropogenic intervention increases at the sites, a decrease is observed in the richness and abundance of taxa associated with higher water quality.

However, this information should be interpreted with caution, as it is recommended to conduct specific studies on macroinvertebrate biodiversity in each area, considering additional ecological factors such as seasonal variability and the ontogenetic stages of organisms, which can significantly influence the results obtained.

FLOW WITH FLOW METER

Overall, a high dispersion in the recorded flow values was observed. The flow meters showed considerable variation, which prevents the identification of a clear pattern in flow dynamics. These fluctuations could be associated with differences in precipitation levels or intermittent discharges (Figures 3 and 4).

At sites MAC1, EU1, and EU2, unstable peaks in flow levels were recorded, which temporally coincide with periods when, according to local residents, the upstream water dam—located

approximately 2 km above the monitoring points—is opened. These events also correspond to periods of higher rainfall in the area, suggesting a possible interaction between natural and anthropogenic factors affecting the local hydrological regime.
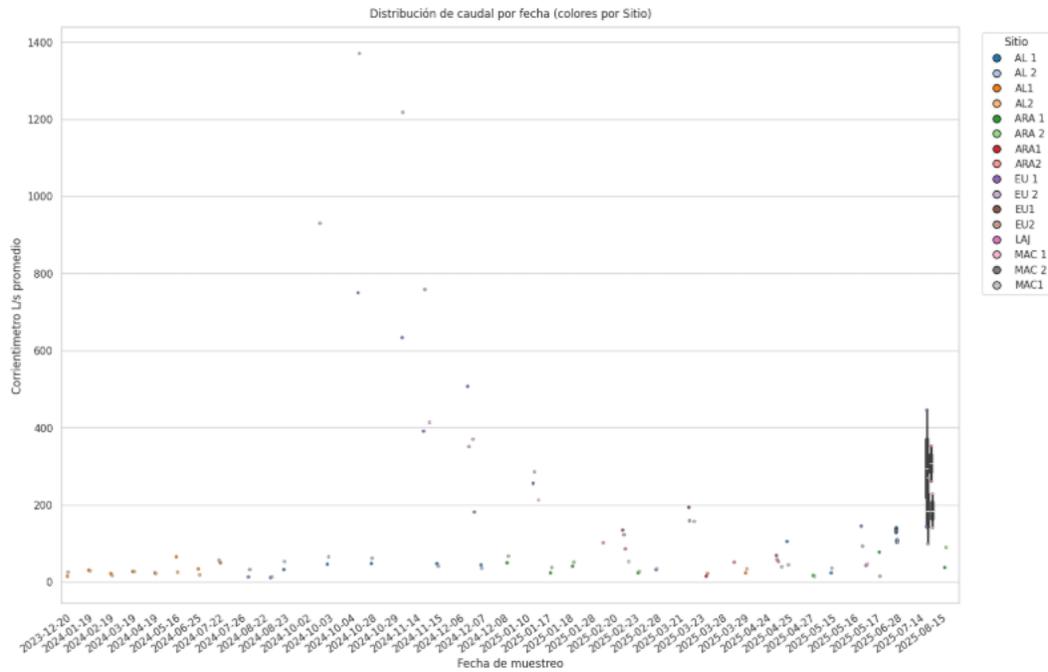

Figure 3: Flow distribution by sampling date. The figure shows the variation in flow recorded on different dates and monitoring sites. Each color represents a different sampling point, highlighting the dispersion of values across the evaluated areas. Marked fluctuations are observed at some sites, suggesting the influence of climatic and anthropogenic factors on flow dynamics.
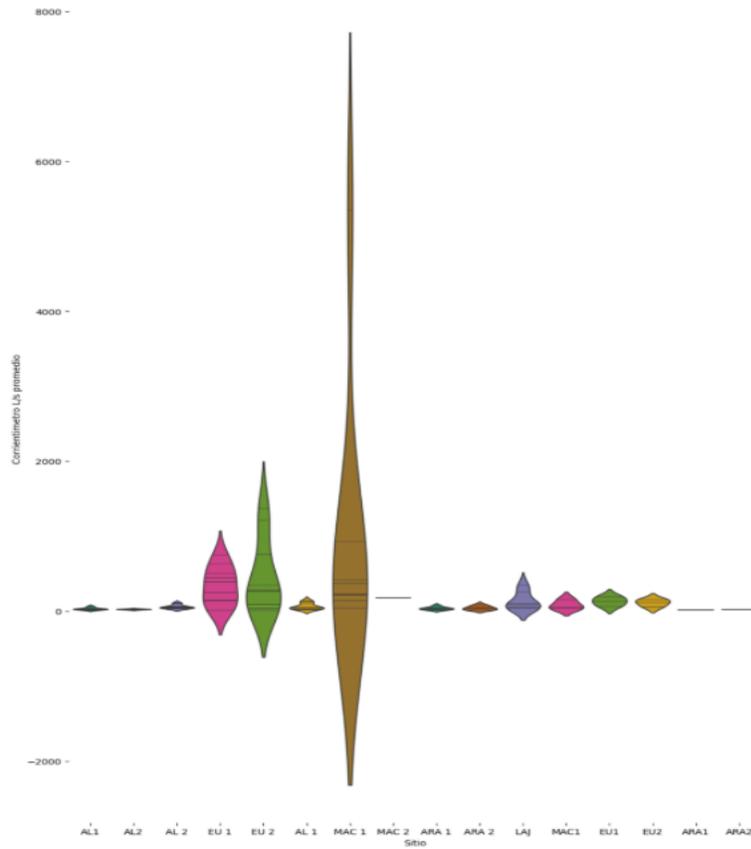
Figure 4: Average flow meter readings (L/s) per site.

BACTERIOLOGICAL ANALYSIS

The results show significant differences in E. coli concentrations between sites ARA1 and ARA2 (Figure 5), while no statistically significant differences were observed for total coliforms (Figure 6). Consistently, site ARA1 presented lower E. coli values throughout the sampling period compared to ARA2.

The highest E. coli peaks were recorded at ARA2 during periods of heavy rainfall, suggesting that rainwater facilitates the transport of organic matter and contaminants into the water body. This trend can be explained by the presence of an unregulated drainage outlet located between ARA1 and ARA2, which discharges directly into the river without prior treatment. This point source of contamination is reflected in the marked increase of E. coli at ARA2, particularly during rainy periods.

Overall, these results demonstrate a direct influence of human activities on the microbiological quality of water. While ARA1 maintains relatively stable conditions, ARA2 shows water quality deterioration linked to uncontrolled discharges and precipitation events that intensify bacterial contamination.
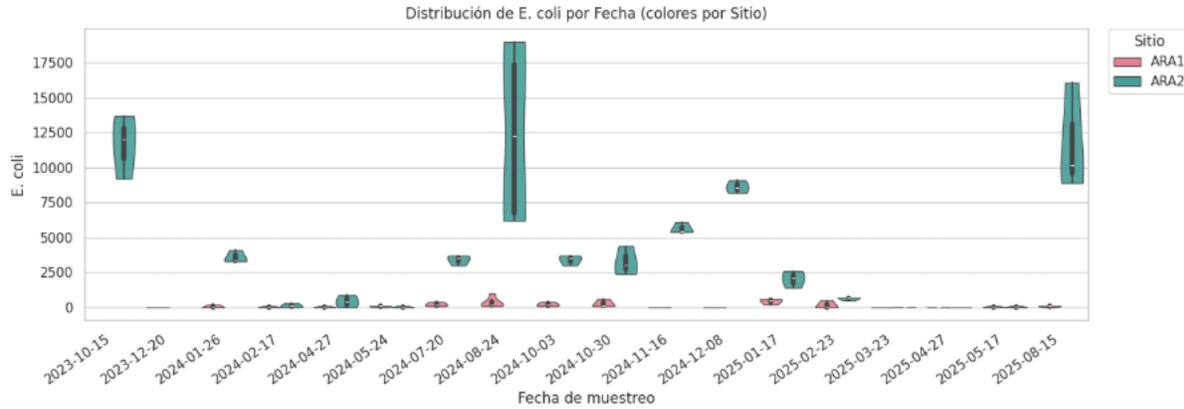
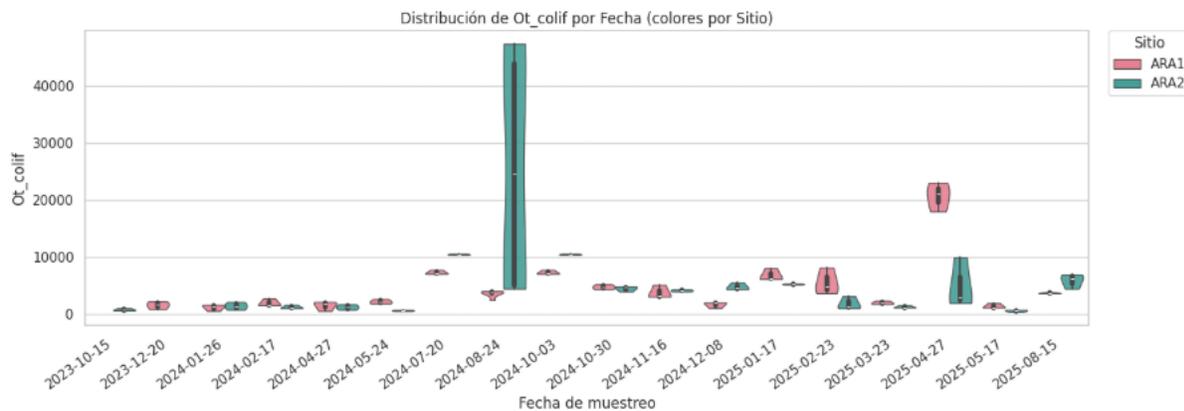Figure 5: Distribution of E. coli at the sites corresponding to ARA1 and ARA2.

Figure 6: Distribution of other coliforms at the sites corresponding to ARA1 and ARA2.

PHYSICOCHEMICAL ANALYSIS

TOTAL DISSOLVED SOLIDS (TDS)

Considering all sampling events, significant differences were found in total dissolved solids (TDS) values between sites AL1 and AL2. Both sites presented the lowest TDS values, indicating better water quality compared to other evaluated areas. According to SEMARNAT standards (2021), concentrations below 25 mg/L correspond to excellent water quality, while values below 75 mg/L are classified as good quality. In this sense, all analyzed sites fall within acceptable ranges, although with notable variations among them.

Higher TDS levels were observed at sites ARA1 and ARA2, located in areas with pine-oak forest cover (Figures 7 and 8). This pattern suggests a possible relationship between vegetation type and the capacity of water bodies to retain or filter sediments. In contrast, sites with montane cloud forest (AL1 and AL2) appear to provide greater natural filtration capacity, reducing the transport of solids into the aquatic system. These results raise discussion on the role of different forest covers in regulating water quality and conserving associated aquatic ecosystems.

Figure 7: Total Dissolved Solids (TDS) recorded on different sampling dates. The red line indicates the threshold value corresponding to excellent water quality according to SEMARNAT (2021) criteria. Values exceeding this line are classified within the range of good water quality.
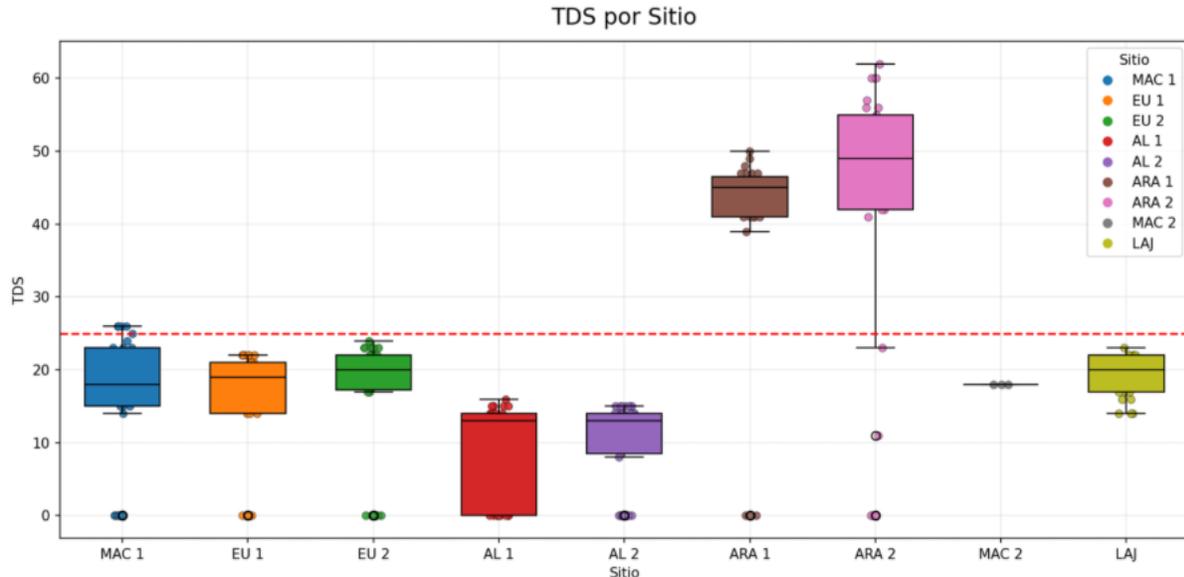

Figure 8: Total Dissolved Solids (TDS) recorded across different sampling zones. The red line indicates the threshold value corresponding to excellent water quality according to SEMARNAT (2021) criteria. Values exceeding this line are classified within the range of good water quality.

CHEMICAL OXYGEN DEMAND (COD)

Chemical Oxygen Demand (COD) is a measure of the amount of oxygen required to chemically oxidize the organic matter present in water. This parameter is widely used to assess water quality and estimate pollutant loads in natural water bodies and wastewater treatment systems (APHA, AWWA & WEF, 2017).

Considering all sampling events and according to SEMARNAT (2021) criteria, the recorded concentrations at all evaluated sites remained below 20 mg/L (Figure 9), indicating that the water at these points meets the quality parameters established by regulations. The date 03/10/2024 corresponds to the highest COD levels recorded throughout the monitoring period (Figure 10), which could be related to specific factors such as organic matter runoff, surface discharges, or variations in climatic conditions prior to sampling. On other dates, values remained below SEMARNAT limits, indicating favorable water quality conditions. Consequently, the analyzed sites can be classified within the good to excellent quality categories.

It is important to note that, according to the same standard, values above 40 mg/L indicate contamination; however, none of the evaluated sites reached these levels. Nonetheless, it is essential to maintain continuous monitoring of the sampling sites, as periodic assessments allow for the detection of potential variations in water quality over time. This practice helps prevent environmental and health risks and provides up-to-date information to support decision-making and the implementation of strategies aimed at conserving and continuously improving water quality indices.
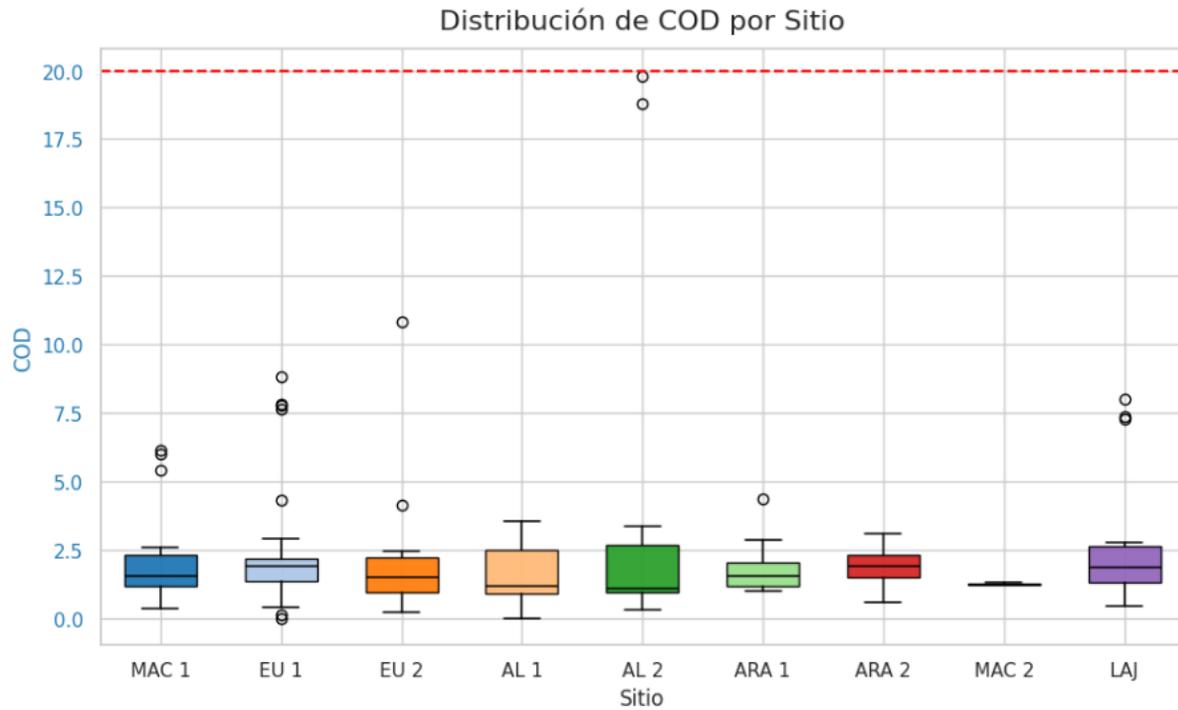

Figure 9: Distribution of Chemical Oxygen Demand (COD) values recorded at the different sampling sites during the study period.
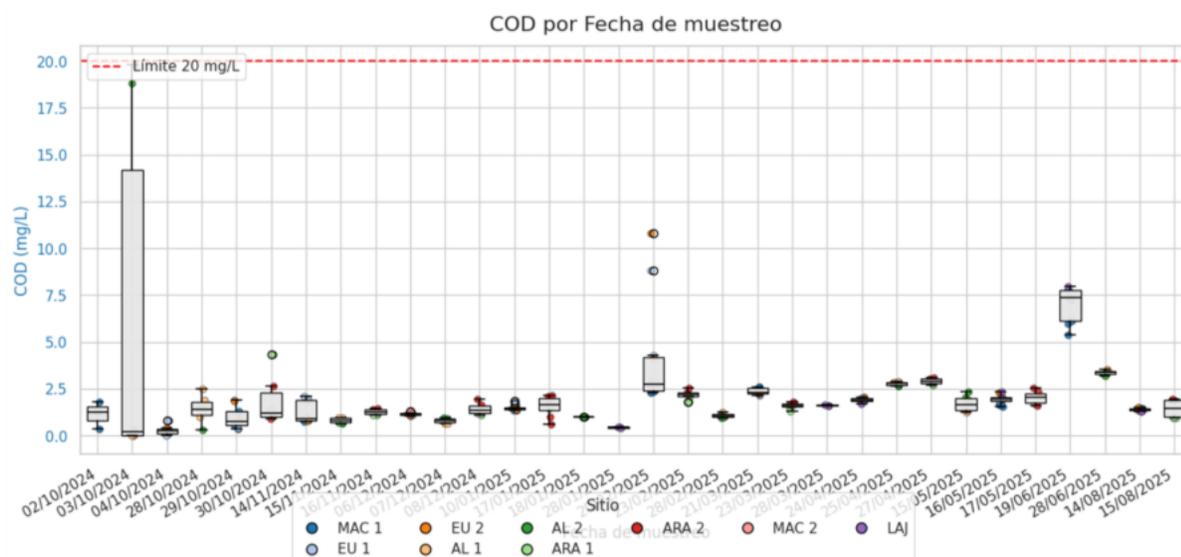
Figure 10: Temporal variation of COD values across the different sampling dates.

TOTAL ORGANIC CARBON (TOC)

Total Organic Carbon (TOC) represents the total amount of carbon present in dissolved or suspended organic compounds in water and is used as an indicator of organic contamination and treatment process efficiency (APHA, AWWA & WEF, 2017).

According to this reference, all evaluated sites exceed the recommended limit, meaning the water is not considered suitable for consumption. Among the sampling points, sites AL2 and EU2 showed the highest TOC concentrations, indicating a greater load of dissolved organic matter and, therefore, a higher degree of contamination (Figures 11 and 12). These results suggest the presence of possible sources of organic input, such as domestic discharges, agricultural activity, or natural decomposition processes, which may be contributing to the increase of this parameter in these areas.
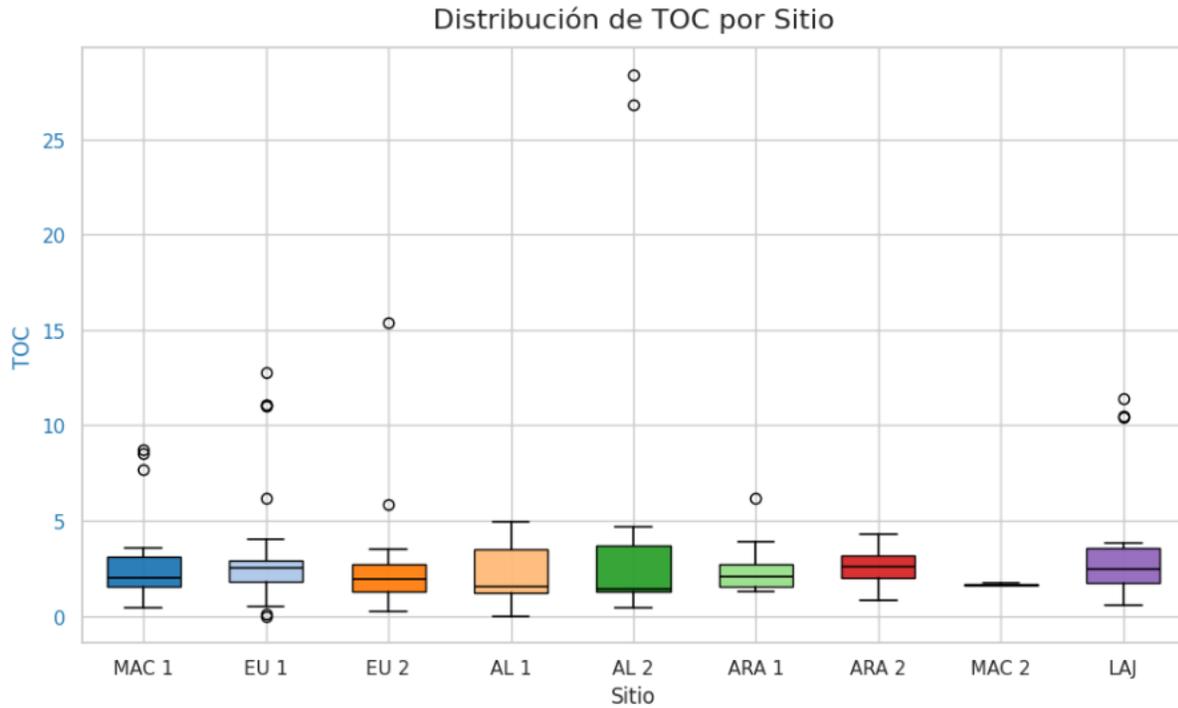
Figure 11: Distribution of Total Organic Carbon (TOC) values recorded at the different sampling sites during the study period.
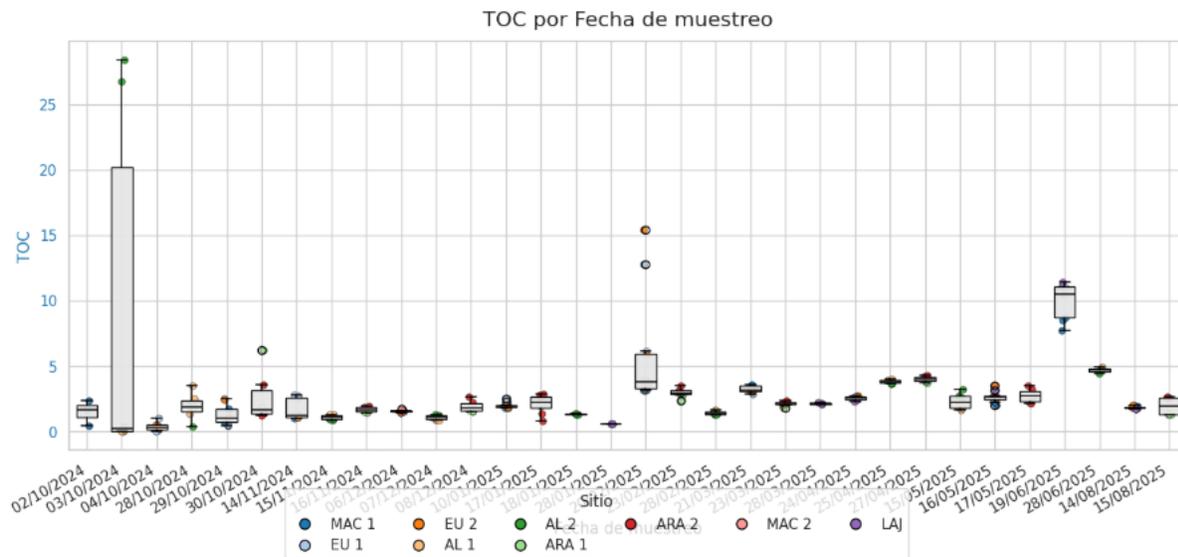

Figure 12: Temporal variation of TOC values across the different sampling dates.

UV275 ABSORBANCE

Similar to Total Organic Carbon (TOC), the UV275 parameter measures ultraviolet light absorption at a wavelength of 275 nm, allowing the detection of dissolved organic substances, aromatic hydrocarbons, and other compounds derived from organic matter in water. This parameter is used as an indirect indicator of organic contamination, as higher absorbance is associated with higher concentrations of organic pollutants (APHA, AWWA & WEF, 2017).

Although no permissible limits are established in Mexican or international standards for this parameter, interpretation is based on relative comparisons between sites. In this context, sites AL2, EU1, EU2, and MAC1 showed the highest UV275 values, indicating a greater load of organic matter and, therefore, a higher level of contamination at these locations (Figures 13 and 14).
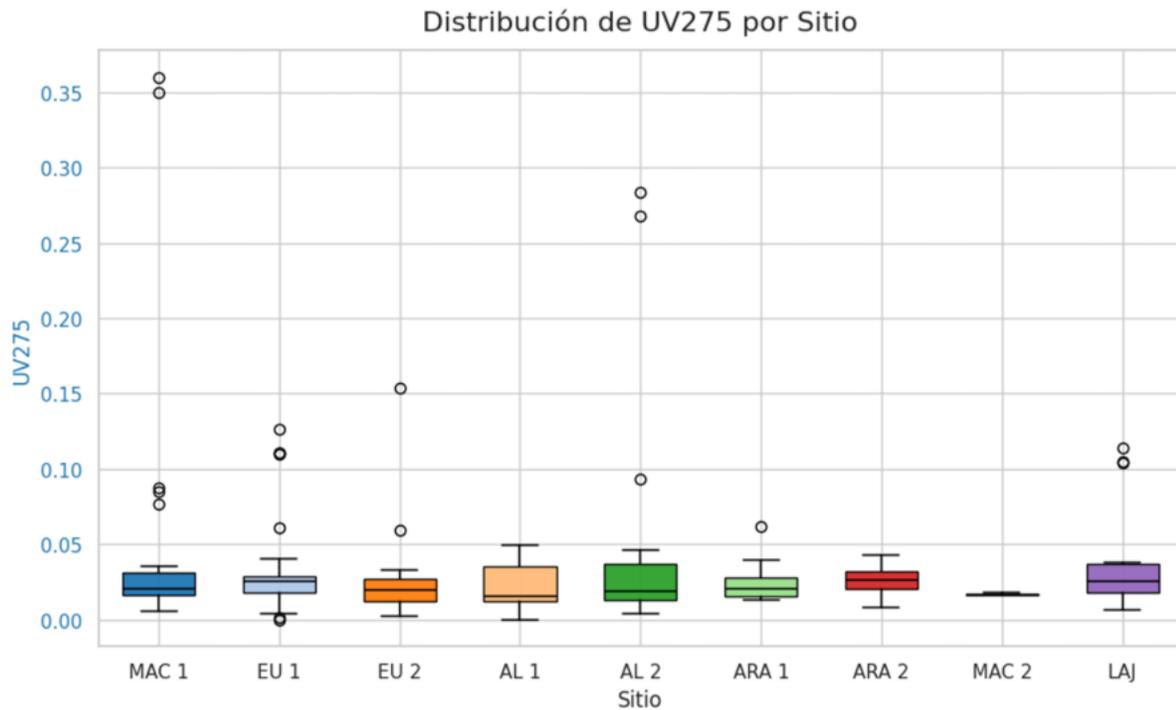

Figure 13: Distribution of UV275 absorbance values recorded at the different sampling sites.
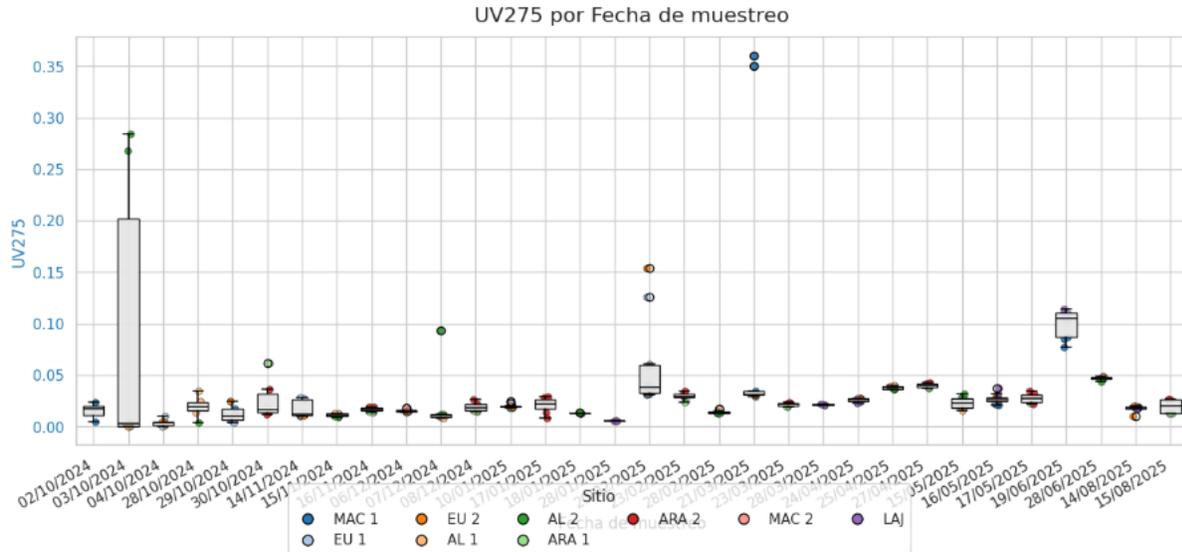
Figure 14: Temporal variation of UV275 absorbance values across the different sampling dates.

GENERAL INDICATOR OF WATER QUALITY

Overall, the results show that most evaluated sites have water quality ranging from acceptable to excellent, according to the parameters analyzed during the sampling period. However, three specific points (AL2, EU1, and EU2) recorded values indicative of contamination (Figure 15).

This condition could be associated with temporary or environmental factors, such as surface runoff or heavy rainfall events, which facilitate the transport of sediments and organic matter into water bodies, temporarily increasing contaminant levels. Nevertheless, the results suggest that, in general, water quality in the study area remains within favorable ranges. It is recommended to continue periodic monitoring to detect potential variations and prevent deterioration at the most sensitive sites.
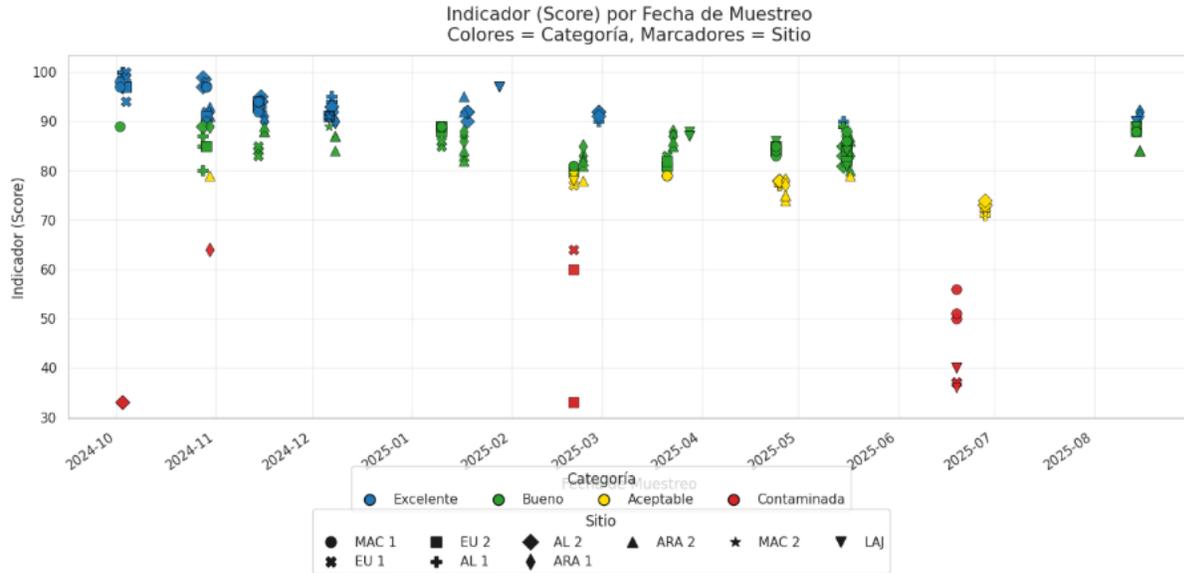
Figure 15: Contamination indicator by sampling date. Colors represent water quality categories according to the degree of observed contamination (Blue: Excellent, Green: Good, Yellow: Acceptable, Red: Contaminated). The markers indicate specific sampling sites, allowing visualization of the spatial and temporal variation of water quality throughout the study period.

CONCLUSION

Overall, water quality at the evaluated sites was classified as acceptable to excellent, based on physicochemical, microbiological, and biomonitoring analyses. Significant differences were observed between sites AL1 and AL2 in biomonitoring parameters and total suspended solids (TSS), suggesting local variations in environmental conditions.

Sites AL2, EU1, and EU2 showed the most evidence of biological and organic contamination, reflected in high levels of *E. coli*, total organic carbon (TOC), and UV275 absorbance, along with a lower number of taxa. These conditions could be due to rainfall events or surface runoff that generate point discharges and transport organic matter into water bodies.

Nevertheless, all sites remained below the limits established in NOM-001-SEMARNAT-2021 for chemical oxygen demand (COD), total dissolved solids (TDS), and electrical conductivity (EC), indicating that, in general, the monitored waters remain within acceptable quality standards. However, TOC values exceeded the European threshold of 500 ppb C, highlighting the presence of dissolved organic matter and indicating conditions unsuitable for direct human consumption.

The comprehensive analysis of parameters suggests that water quality in the study area is predominantly good, although localized deterioration was detected, associated with anthropogenic

pressures and natural seasonal runoff processes. These results underscore the need to implement targeted management and control measures at the most vulnerable sites to prevent medium-term environmental degradation.

While this study provides a preliminary overview of anthropogenic influences on the ecological dynamics of the evaluated water bodies, it is essential to maintain continuous and long-term monitoring. Sustained studies over time will allow for a more precise understanding of how human activities affect the structure and functioning of ecosystems associated with the cloud forest. This will generate key information to guide conservation strategies and the sustainable management of these sensitive environments.

REFLECTION ON COMMUNITY PARTICIPATION IN CLOUD FOREST CONSERVATION

Effective conservation of the Montane Cloud Forest (MCF) depends not only on governmental or institutional actions but also on the active commitment of the local community, who are the primary beneficiaries and guardians of these ecosystems. In this context, the program implemented by FIDECOAGUA represents an exemplary model of community participation, where forest owners receive economic incentives through Payments for Environmental Services (PES), promoting the protection of over 1,400 hectares of MCF. This scheme not only ensures forest cover conservation but also fosters environmental education and awareness regarding the importance of ecosystem services, including potable water provision and natural resource regulation.

The participation of the Forest Guardians, along with collaboration from local communities and volunteer university students, enabled active and strategic monitoring of water quality and associated ecosystems, providing reliable information on flow rates, biomonitoring, and physicochemical and microbiological parameters. This direct involvement generates tangible and ancillary benefits: it strengthens local governance, promotes sustainable practices in agriculture and livestock, and contributes to resilience against natural events such as heavy rainfall or runoff.

Furthermore, partnerships with academic institutions, civil society organizations, and private companies enhanced conservation efforts by providing technical support, outreach, reforestation projects, and stable funding. This multi-stakeholder collaboration ensures that the community receives not only economic benefits but also develops technical skills and environmental awareness, consolidating its role as a key actor in forest preservation and sustainable water resource management.

In conclusion, the FIDECOAGUA case demonstrates that community participation is fundamental for achieving lasting impact in the protection of the MCF. The integration of local residents in ecosystem monitoring and management ensures that conservation actions are not sporadic but

sustained over time, strengthening ecological resilience and promoting sustainable local development in harmony with nature.

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