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Women, water, and conservation:
Co-design of environmental zoning scenarios

Mujeres, agua y conservación:
Co-diseño de escenarios de zonificación ambiental

Mulheres, água e conservação:
Co-projetando cenários de zoneamento ambiental

Les femmes, l'eau et la conservation :
Co-conception de scénarios de zonage environnemental

Fuente: Autoría propia

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Abstract

The rural water supply system provides ecosystem services (ES) that are essential to the well-being of communities. Women play a crucial role in the provision and protection of water in these systems. However, water management plans often do not adequately integrate ecosystem benefits or recognize the role of women in rural land-use planning. This study aimed to advance participatory design zoning scenarios with a focus on ES and gender perspectives. To this end, the supply and demand of ES were evaluated through spatial models, the role of women in the management of aqueducts and ES was characterized, and environmental zoning scenarios were formulated for rural aqueducts. The results highlight the importance of women's participation in water conservation and community management of ES. It is evident that the current land use planning efforts, focused on watershed protection and optimization of water services, have not sufficiently addressed gender issues and their role in water conservation. This study highlights the need for more inclusive approaches that promote women's participation in decision-making, environmental conservation, and planning. Strategic land management around water requires an informed and engaged population, which is crucial for ensuring appropriate environmental management scenarios according to the reality of the territory.

Keywords: community participation, rural women, ecosystem services, governance, medio ambiente

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Resumen

Los acueductos rurales ofrecen servicios ecosistémicos (SE) esenciales para el bienestar de las comunidades locales. La mujer juega un papel crucial en la provisión y protección del agua. No obstante, los instrumentos de gestión del agua a menudo no integran adecuadamente los beneficios de los ecosistemas ni reconocen el rol de la mujer en la definición de zonas de interés para el ambiente. Este estudio avanza en el diseño participativo de escenarios de zonificación ambiental con énfasis en el mapeo de SE y perspectiva de género. Para ello, se evaluó la oferta y demanda de SE a través de modelos espaciales, se caracterizó el rol de la mujer en la gestión de los acueductos y los SE, y se formularon escenarios de zonificación ambiental. Se evidenció que los actuales esfuerzos de planificación del uso del suelo, centrados en la protección de cuencas hidrográficas y la optimización de servicios hídricos, no han abordado de manera suficiente las cuestiones de género y su papel en la conservación del agua. La ordenación estratégica del territorio alrededor del agua requiere una población informada y comprometida, lo cual es fundamental para garantizar escenarios de gestión ambiental adecuados a la realidad en el territorio.

Palabras clave: participación comunitaria, mujer rural, servicios ecosistémicos, gobernanza, gestión ambiental

Resumo

Os aquedutos rurais fornecem serviços ecossistêmicos (SE) essenciais para o bem-estar das comunidades. As mulheres desempenham um papel fundamental no fornecimento e na proteção da água nessas áreas. No entanto, os planos de gestão da água frequentemente não integram adequadamente os benefícios dos ecossistemas nem reconhecem a contribuição das mulheres no planejamento ambiental. Este estudo propõe a concepção participativa de cenários de zoneamento ambiental, com ênfase nos SE e uma abordagem de gênero. Para isso, foram avaliadas a oferta e a demanda de SE por meio de modelagem espacial, além de caracterizado o papel das mulheres na gestão dos aquedutos e dos SE. Cenários de zoneamento ambiental foram, então, formulados. O estudo evidenciou que os esforços atuais de ordenamento do território, focados na proteção de bacias hidrográficas e na otimização dos serviços hídricos, ainda não abordam de forma adequada as questões de gênero e sua relevância na conservação da água. A gestão estratégica do território em torno dos recursos hídricos exige uma população informada e engajada, sendo essencial para a construção de cenários de gestão ambiental que reflitam a realidade local.

Palavras-chave: participação comunitária, mulheres rurais, serviços ecossistêmicos, governança, gestão ambiental

Résumé

Les aqueducs ruraux fournissent des services écosystémiques essentiels au bien-être des communautés, et les femmes jouent un rôle crucial dans leur approvisionnement et leur préservation. Cependant, les plans de gestion de l'eau négligent souvent d'intégrer pleinement les bénéfices des écosystèmes et sous-estiment le rôle des femmes dans la planification environnementale. Cette étude vise à promouvoir une approche participative dans la création de scénarios de zonage environnemental, en mettant en avant les services écosystémiques et en intégrant la parité entre les genres. À cette fin, une évaluation spatiale de l'offre et de la demande de services écosystémiques a été réalisée, le rôle des femmes dans la gestion des aqueducs et des services écosystémiques a été caractérisé, et des scénarios de zonage environnemental ont été développés. Les résultats révèlent que les efforts actuels de planification de l'utilisation des terres, axés sur la protection des bassins versants et l'optimisation des services d'eau, n'intègrent pas suffisamment les enjeux liés au genre et leur importance pour la conservation de l'eau. Une gestion stratégique des terres autour de l'eau, qui requiert une population informée et engagée, est essentielle pour garantir des scénarios de gestion environnementale adaptés aux réalités locales.

Mots-clés : participation communautaire, femmes rurales, services écosystémiques, gouvernance, gestion environnementale

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Women, water, and conservation:
Co-design of environmental zoning scenarios

Introduction

The global water crisis has increased vulnerabilities in water supply systems, underscoring the urgent need for integrated water resource management, particularly in rural areas (UN, 2024). Proper water management involves the conservation of areas where water is sourced and distributed, making watershed planning a key tool for the sustainable planning and management of water resources (Wang et al., 2016).

Efficient water use planning requires the development of scenarios that integrate various territorial elements and take into account ecosystem services (ES), as well as the active participation of local stakeholders. This approach ensures more equitable access to information and fosters informed, participatory decision-making (Vollmer et al., 2022). However, in rural settings, the low level of women's participation in such processes reflects deep-rooted gender inequalities, which limit their capacity to influence key decisions regarding water use (Rivera, 2016).

Gender is a significant factor in the management of natural resources, as men and women interact with these resources in different ways (McDowell, 2000). Women, often directly responsible for managing resources such as water and agriculture, possess a unique perception of environmental changes and actively contribute to the implementation of strategies for better use and conservation (Laurie, 2011; Leongómez, 2024). Despite their crucial role in water conservation and the management of ecosystem-derived benefits (Saad, 2024), their perspectives remain underrepresented in water use planning—particularly in low-income countries with high levels of land access inequality (Silva Rodríguez de San Miguel, 2018).

Gender geography explores power relations, cultural practices, and the use of communal geographic spaces (Bowlby et al., 2023). Women play a central role in water use, especially in rural communities. Nevertheless, they face persistent barriers that limit their access and participation in environmental decision-making (Kakinuma & Wada, 2024). Social mapping is a participatory methodology that facilitates the incorporation of gender perspectives into water management by directly integrating local perceptions (Barragán Giraldo, 2016; Arrillaga, 2018).

In Colombia, community-managed water systems supply water to rural populations and are governed by informal usage rules aimed at ensuring equitable and sustainable access to water (Ramírez, 2024). However, local participation in defining areas of conservation interest remains limited. This study aims to design environmental zoning scenarios with a gender-sensitive approach in rural aqueduct areas within the Timbío River watershed, with the objective of recognizing the active role of women in ecosystem management—aligned with the Sustainable Development Goal on Clean Water and Sanitation (Bhaduri et al., 2016). The research advances in three areas: evaluating ES in the region, characterizing the role of women in the use and management of these services, and proposing a zoning scenario that promotes equitable participation in the conservation and management of water catchment systems in rural settings.

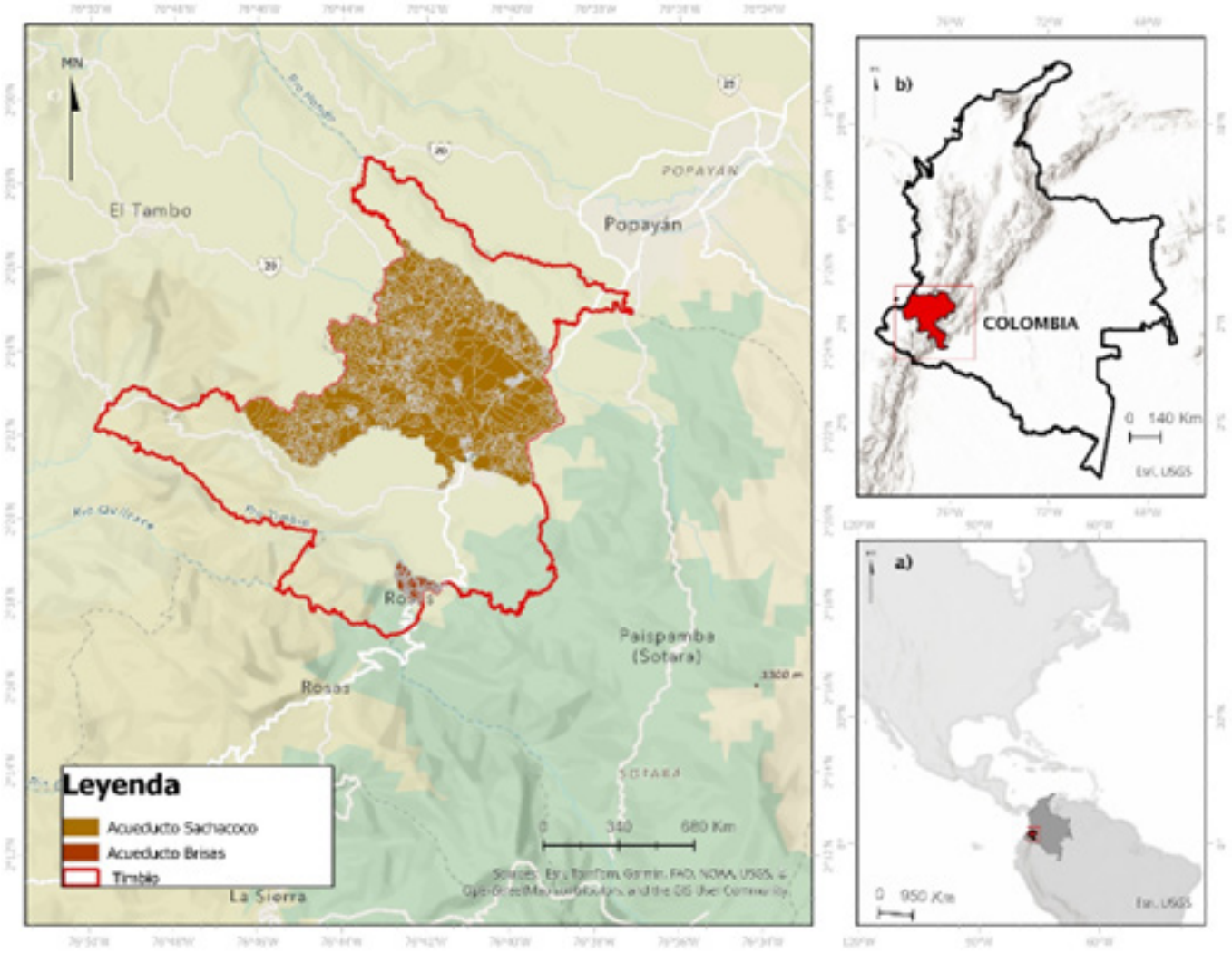

Figura 1. Required Inputs for Ecosystem Services Mapping
Fuente: Own compilation.

Methodology

Study Area

The Timbío River sub-watershed, vital to the municipality of Timbío, spans the territories of Timbío, Sotará, and El Tambo. This sub-watershed is essential not only for the municipality's water supply but also for the region's biodiversity and cultural heritage. Land cover distribution within the watershed is classified into urbanized areas (0.38%), agricultural land (61.6%), forests and semi-natural areas (37.9%), and wetlands (0.12%).

The sub-watershed plays a critical role in sustaining ecological integrity and local livelihoods. However, it faces significant challenges such as pollution and deforestation, highlighting the urgent need for protection and sustainable management to ensure the well-being of the region (see Figure 1).

Ecosystem Services Supply Estimation

The evaluated ecosystem services included annual water yield, carbon storage, edge effect on forest carbon storage, nutrient retention rate, habitat quality, and tourism potential (see Table 1). The mapping of ecosystem services was conducted using the *Integrated Valuation of Ecosystem Services and Tradeoffs* (InVEST) software (Salata et al., 2017).

Characterization of the Role of Women in Ecosystem Service Use and Rural Aqueduct Management

This characterization was conducted through a survey focused on socioeconomic and perception-related aspects. The survey was administered to residents within the study area using snowball sampling across the various *veredas* (rural districts) served by the Sachacoco

Ecosystem Service	Definition	Necessary inputs	Methodology / source	Format
Annual water production	The InVEST water yield model estimates the amount of water produced in a watershed, identifying how changes in land use and vegetation cover affect the annual surface water yield.	Land Use and Land Cover (LULC) map	Adaptation of Corine Land Cover, 2018, Republic of Colombia, scale 1:100,000. The map was rasterized and clipped to the study area	Raster
		Watershed boundary delineation	Developed using a drainage layer from Corpocauca that allows distinguishing different watersheds.	Vector
		Average annual evapotranspiration	Global data of aridity index and potential evapotranspiration v3, clipped to the study area.	Raster
		Average annual precipitation	Station data in the study area, used to generate an annual precipitation map in QGIS. Source: IDEAM.	Raster
		Root restriction depth	Data from the Harmonized World Soil Database (HWSD).	Raster
		Plant Available Water Content (PAWC)	HWSD data, referenced for the study area.	Raster
		Biophysical table	Data such as root depth, KC, and the Z parameter value from the FAO global soil properties database.	CSV
Carbon Storage	The InVEST carbon storage model estimates and maps the amount of carbon stored in different ecosystems. This model helps evaluate how changes in land use and land management affect the capacity of ecosystems to store carbon.	Land Use and Land Cover (LULC) map.	The LULC map was downloaded from Colombia en mapas and a value was assigned to each land cover type before rasterizing and clipping it to the study area. Adaptation of Corine Land Cover. Republic of Colombia. Scale 1:100,000. Period 2018.	Raster
		Biophysical Table	The reference values in the biophysical table were taken from the Intergovernmental Panel on Climate Change's (IPCC) 2006 guidelines and from other global soil maps and databases (FAO).	CSV
Nutrient discharge rate	The InVEST nutrient delivery ratio model determines the amount of nutrients, such as nitrogen and phosphorus, that are discharged into water bodies from different parts of a watershed.	Land Use and Land Cover (LULC) map.	The LULC map was downloaded from "Colombia en Mapas" and each land cover type was assigned a value. The map was then rasterized and clipped to the study area. Adapted from Corine Land Cover. Republic of Colombia. Scale 1:100,000. Period: 2018	Raster
		Watershed boundary delineation	The watershed boundary delineation was created using a drainage layer from Corpocauca, which included an attribute that allowed us to distinguish the different watersheds in the Cauca region. Source: Corporación Autónoma Regional del Cauca (Corpocauca).	Vector
		Digital Elevation Model (DEM)	The digital elevation model was generated in QGIS using contour lines obtained from open data provided by IGAC (Instituto Geográfico Agustín Codazzi) at a scale of 1:100,000.	Raster
		Average Annual Precipitation.	Annual precipitation data from various stations within the study area were used. Using this data, an annual precipitation map was created with QGIS software. Source: IDEAM. – Hydrometeorological data download	Raster

Servicio Ecossitemico	Definición	Insumos Requeridos	Metodología/Fuente	Formato
Habitat quality.		Land Use and Land Cover (LULC) map.	The LULC map was downloaded from "Colombia en mapas" and a value was assigned to each land cover type before rasterizing and clipping it to the study area. Adaptation of Corine Land Cover. Republic of Colombia. Scale 1:100,000. Period 2018.	Raster
	The InVEST habitat quality model evaluates habitat quality in a given landscape, considering how human activities and land use changes affect biodiversity and ecosystem services.	Threats Table	The threats table contains the name of each threat, the maximum impact distance for each one, the weight was subjectively assigned by the researchers, and the decay was taken from the literature. Source: The mining and hydrocarbons areas layer from Colombia en mapas was used as the basis for developing the threats map.	CSV
		Mean saturation constant (k)	The default value provided by InVEST was used as a reference.	Numero
		Folder with the threat data.	Each of the threats used was spatially mapped within the watershed and subsequently converted into raster format.	Raster
Recreation and tourism	Determines the supply of tourism and recreation activities related to the use of nature	Land Use and Land Cover (LULC) map.	A literature review was conducted to identify tourist and cultural sites. The locations were organized by type (ecotourism, sport fishing, hiking, etc.) and mapped as a point layer in QGIS.	Vector

Table 1. Required Inputs for Ecosystem Services Mapping
Source: Own compilation.

and Brisas rural aqueducts. The questionnaire was organized into sections covering: general information about the respondent, property-related data, perceptions regarding conservation in aqueduct areas, and gender-related aspects such as economic activities, number of children, and whether the respondent was the head of household, among others. Perceptions were evaluated using a Likert scale ranging from 0 to 5, where 0 indicated low perception and 5 indicated high perception (Gädicke Robles et al., 2017).

Development of Participatory Environmental Zoning Scenarios

A social cartography approach was applied to identify geographic features, natural resources, infrastructure, and housing distribution. The workshops were coordinated by the Administrative Board of the rural aqueduct, which facilitated significant community participation due to their close engagement with aqueduct-related activities. During the mapping workshops, participants discussed proposals and potential interventions to better understand local efforts aimed at addressing water conservation challenges and promoting sustainable practices within the communities.

Environmental Zoning

The information gathered in the previous stages was integrated through spatial analysis using QGIS and ArcGIS Pro, to generate the environmental zoning map for the areas of influence of the rural aqueducts. This zoning incorporates environmental determinants established by the Regional Autonomous Corporation of Cauca (CRC), as well as strategic areas for water resource conservation and protected zones. Additionally, it considers land use guidelines established in Chapter 1, Title 3 of the Basic Land Use Plan (PBOT) as outlined in Agreement 016 of 2022 of the Municipality of Timbío.

The defined zones were: (1) strict preservation zones, (2) production zones, (3) rural service road corridors, and (4) ecotourism, recreation, and relaxation zones. Strict preservation zones include reservoirs, watercourses, forests, wetlands, and key areas for the protection of water resources. For rivers, a 20-meter protective buffer was established along the banks, while for springs and streams, a 10-meter perimeter was defined around the water sources. Production zones are designated for human activities that generate goods and services, such as agriculture, livestock farming, forestry, mining, aquaculture, industry,

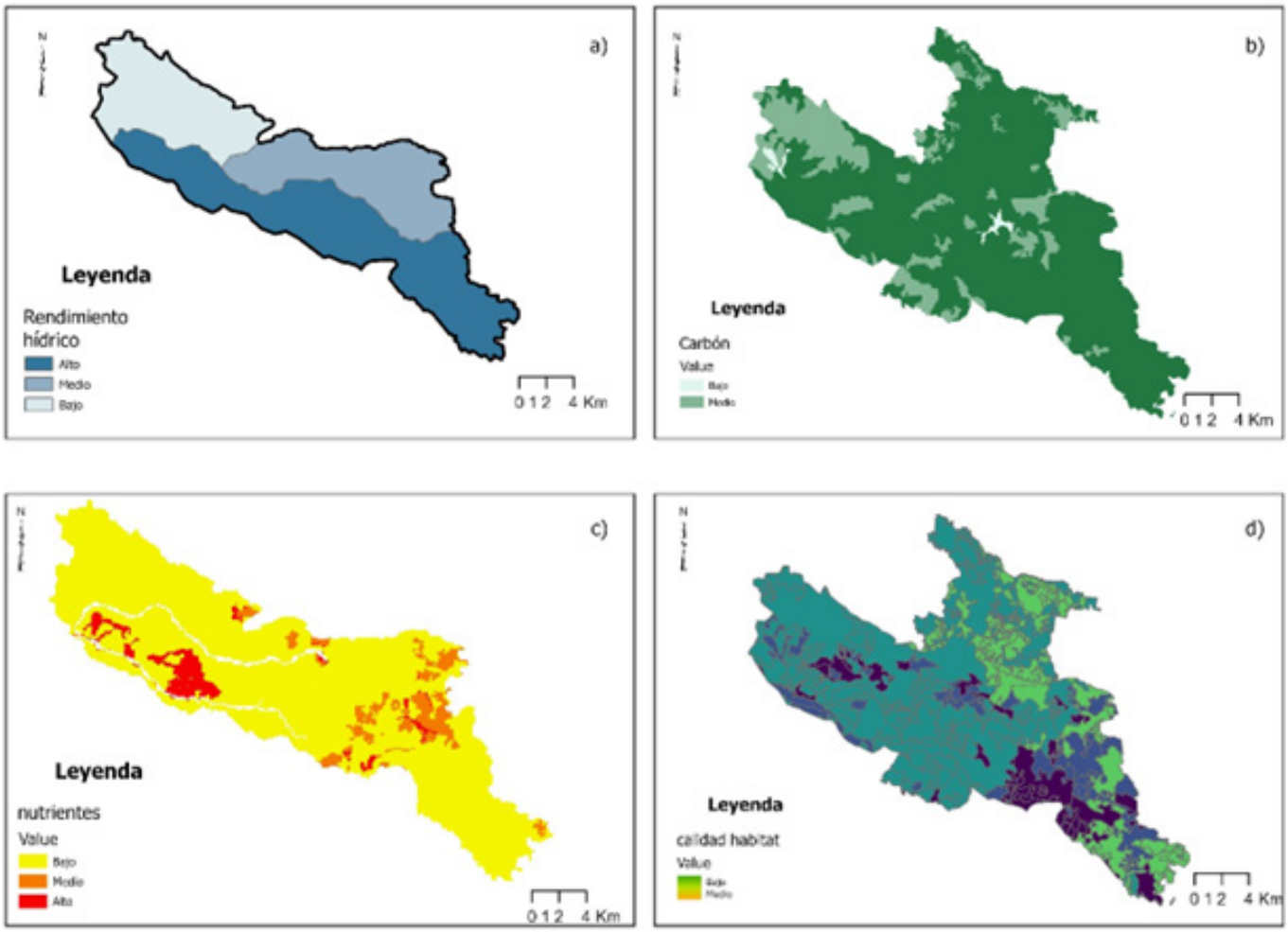

Figure 2. Ecosystem Services: a) water production; b) carbon storage; c) nutrient retention; and d) habitat quality.

Source: Author's own elaboration.

and tourism. These activities must be conducted sustainably, with responsible use of natural resources. For rural service road corridors, a 20-meter-wide ecological buffer zone was proposed parallel to the primary and secondary roads, which represent the main transportation routes of the region. Ecotourism, recreation, and relaxation zones, due to their landscape, environmental, and social value, are intended for leisure and passive recreation activities, ensuring a reasonable and sustainable use of resources.

Results

Ecosystem Services Supply in the Timbío River Watershed

The annual water yield in the Timbío River watershed was 179,081,597.80 m³. The highest values were recorded in the Piedras River sub-watershed, with an estimated yield of approximately 96 million m³ per year, followed by the upper part of the Timbío River sub-watershed, which generates around 58 million m³ annually. In contrast, the lower part of the Timbío River sub-watershed shows a lower water yield. These results reflect an uneven distribution of water resources within the Timbío River watershed, influenced by factors such as the extent of sub-watersheds, topography, vegetation, precipitation, and land use (see Figure 2a).

The results related to carbon storage show a notably diverse distribution depending on land cover type. Areas covered by dense forests, shrublands, and abundant vegetation show the highest values, reaching up to 39,645 tons of carbon per pixel, highlighting the capacity of these ecosystems to efficiently capture and retain carbon. In contrast, areas with crops, grasslands, and herbaceous vegetation show intermediate values of carbon storage, reflecting a moderate capacity to retain carbon compared

sexo	r_edad	l_nacimiento	n_hijos	c_hogar	actividad	n_estudios	tenencia	r_ingresos	a
0.596	4.636	0.68	1.842	0.496	3.202	1.022	0.118	2.794	1.667
0.492	1.467	0.468	1.246	0.501	2.16	0.912	0.324	1.385	1.236
0	1	0	0	0	0	0	0	1	1
1	7	1	6	1	6	4	1	6	5

0=hombre; 1=mujer
1=18 a 20;2=21 a 30=31 a 40; 4=41 a 50; 5=51 a 60; 6=61 a 70; 7=mayor a 70

0= otro; 1=vereda

0=no; 1= si
1=agricultura; 2=ganadería; 3=agricultura y ganadería; 4=hogar; 5=comercio; 6=otro

0=ninguno; 1=primaria; 2=bachillerato; 3: Técnico; 4=universitario

0=otro; 1=propia

1= menos de 500.00; 2=500.000 a 800.000; 3=800.000 a 1'000.000; 4=1'000.000 a 1'200.000; 5=1'200.000 a 1'500.000; 6=más de 1'500.000

1=descanso; 2=recreación;3=deporte; 4=caminar; 5=otros

Table 2. Summary of Socioeconomic Statistics – Sachacoco and Brisas Aqueduct
Source: Own elaboration

to denser natural ecosystems. On the other hand, urbanized areas and rocky outcrops show the lowest values, with less than 8.70 tons of carbon per pixel, mainly due to vegetation loss and soil alteration caused by human development (see Figure 2b).

The discharge rate is 82,484 kg/pixel in areas with lower vegetation cover, less fertile soils, and steeper slopes, which may lead to surface runoff and erosion, reducing the amount of nutrients that reach water bodies. Conversely, the highest nutrient discharge values (1,168.52 kg/pixel) indicate the likely presence of activities such as intensive agriculture with fertilizer use, livestock farming, and deforestation or forest degradation, which significantly contribute to nutrient accumulation and transport to water bodies (see Figure 2c).

The Habitat Quality ecosystem service shows values ranging from 0.160 to 1, with no specific unit of measurement. However, higher values indicate greater habitat quality, while lower values reflect increased ecosystem degradation. The areas with the lowest values present higher levels of threat, including roads, the urban area of Timbío, and mining and hydrocarbon zones (see Figure 2d).

The recreation and tourism ecosystem services map highlights the region's biodiversity, offering visitors immersive experiences in unique natural environments such as the Laguna del Duende and Cerro Pan de Azúcar. The second-highest category in terms of tourism service provision is linked to sport fishing, a practice deeply rooted in local culture, conducted in regional reservoirs and lakes. Third, waterfalls and natural pools also represent significant tourist attractions, ideal for recreational activities in contact with nature (see Figure 3).

The Role of Women in the Use of Ecosystem Services and the Management of Rural Aqueducts

Socioeconomic Characterization

Table 2 presents the main variables of the socioeconomic characterization. According to the surveys, 59% of the population in the study area is female. Additionally, 72% of the population was born in the study area, which suggests a strong sense of belonging.

The demographic profile indicates that 33% of the population is between 51 and 60 years of age, followed by the 41 to 50 age group, which represents 17%. Furthermore, 74% of the population has only basic primary education and empirical knowledge, which is largely associated with the predominance of older individuals in the area.

In terms of employment, 49% of the population works between 5 and 8 hours per day, and of this group, 80% works between six and seven days a week. The women who make up the remaining portion of the population work as homemakers, performing a demanding and essential yet unpaid role. During the coffee harvest, 76% of these women work 8 hours a day, six days a week, making a significant contribution to the labor pattern in the municipality's rural zone.

Periods of high labor activity, such as coffee harvesting or crop cleaning, account for 87% of the total reported activities. During crop growth stages, the population diversifies its activities, turning to commerce or restricting spending to recreational consumption in order to avoid

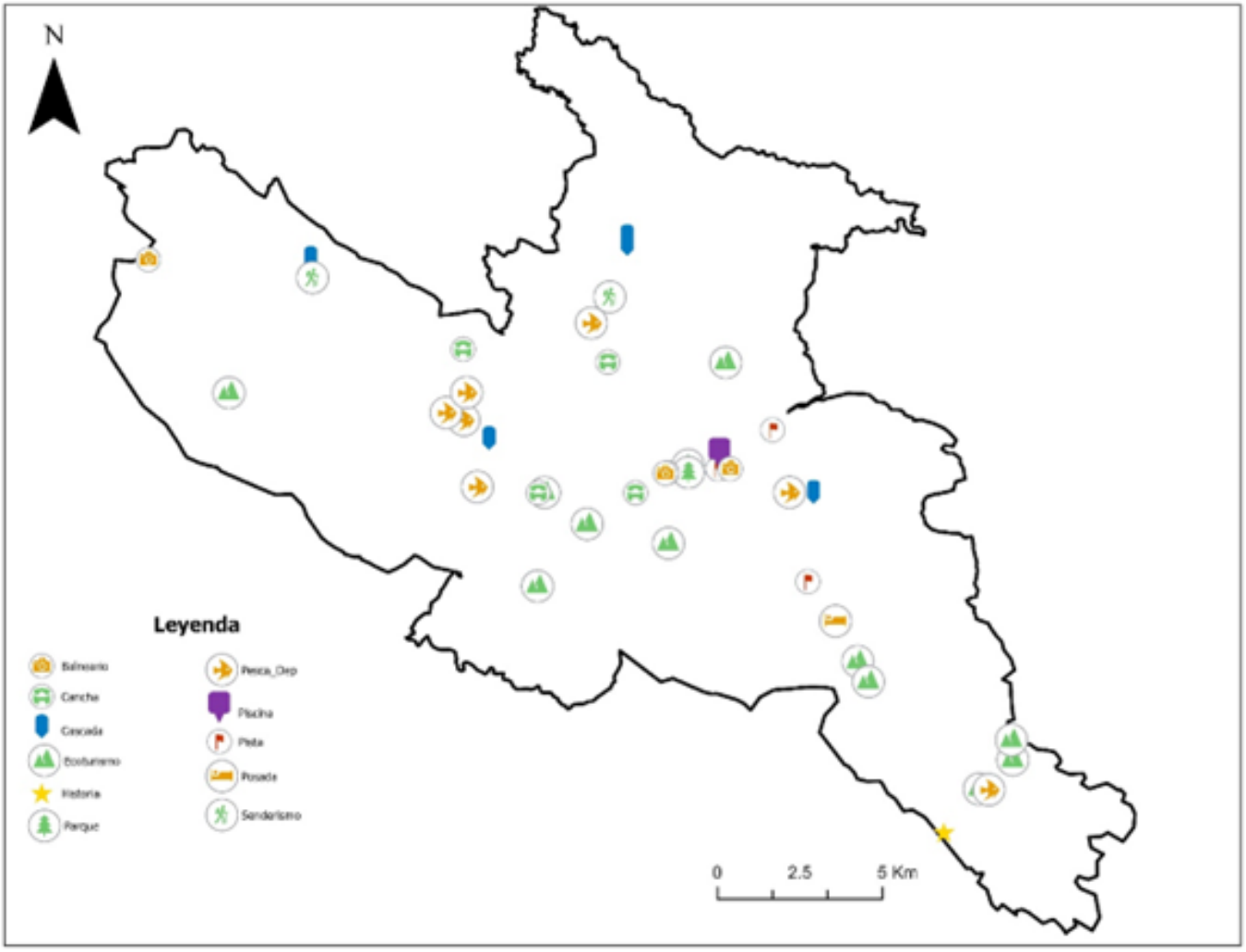

Figure 3. Recreation and tourism services offered.
Source: Author's own elaboration.

additional expenses. The prudent management of financial resources during these periods of lower activity highlights the importance of adapting to agricultural cycles.

The income distribution shows that 50% of the population earns between 500,000 and 1,000,000 Colombian pesos per month. This is largely due to the fact that most people work on their own land and deduct from their income the costs of inputs such as fertilizers and raw materials used in their crops. During coffee harvest seasons, when labor activity is more intense, the daily wage of hired workers ranges between 21,000 and 30,000 pesos.

Perceptions of the Benefits Provided by Nature

The perceived importance of natural resources varies according to the type of services and their everyday relevance to people's lives. Rivers and streams, which are present on only a few properties, received scores between 2 and 3, being considered less important than other landscape elements. However, landowners with access to these water bodies make efforts to conserve them, assigning them greater value in terms of preservation. As for forests, their perceived importance is lower, with scores ranging from 2 to 3, since large forested areas are largely absent and instead exist as small groups of native trees planted to protect watersheds. In contrast, soil, flora, and fauna are considered more relevant, receiving scores between 3 and 4 due to the extensive area dedicated to the cultivation of staple crops in the study area. The importance of preserving forest patches and water springs is also highlighted, as they help sustain the region's biological diversity. Water quantity and quality are highly valued, with an average score of 4.7, attributed to the good quality of water and active management, which ensures a reliable and safe supply for the community.

Perceptions of Impacts on the Natural Conditions of Rural Aqueducts

Impacts on nature were assessed through the question: "Which natural aspects of the *vereda* are being affected?" The results reflect a growing perception of importance regarding various environmental aspects, with scores ranging between 2 and 3. The most frequently mentioned responses referred to the natural conditions of the larger water cycle, especially longer drought periods, and biodiversity loss due to reduced species abundance and variety. The community mainly recognizes changes in temperature and drought periods, while other less prominent impacts include reduced soil fertility. There is genuine concern among landowners about the potential negative effects of certain soil treatments, leading most to take measures to minimize such impacts.

Perceptions of the Benefits Provided by the Rural Aqueduct to the Community

Perceptions of the rural aqueduct's benefits were assessed through the statement: "The benefits provided by the *veredal* aqueduct for ecosystem conservation and your daily activities correspond to." According to the survey results, the continuous availability of water and its adequate quality for domestic use are the main perceived benefits of the aqueduct, with an average score of 4.5 and a standard deviation of 0.7, reflecting high confidence in the responses. In contrast, aspects such as flood control through water flow regulation, habitat provision for aquatic species, proper ecosystem functioning, and monetary income received scores ranging between 1 and 2.2.

Community Participation

The results reflect a broad recognition of the role of women in the protection of natural resources, highlighting the importance of integrating a gender perspective into conservation and environmental management processes. The role of women in managing the rural aqueduct and the value of the activities they perform in its operation are considered vital. Likewise, high values were reported regarding the role of community participation in the conservation of the aqueduct. The residents of the aqueduct area believe that local participation strengthens environmental awareness, fosters the effective implementation of conservation measures, and reinforces social connections and a sense of belonging to the natural environment.

Environmental Zoning Scenario of Rural Aqueduct Areas

The result of the social mapping conducted with the group of women first involved the identification of water tributaries, followed by the delineation of these water bodies—geographical attributes considered essential for water supply and the conservation of both water and natural resources. Next, they identified water springs in the *veredas*, focusing on properties that host the most relevant sources for the aqueduct. Forest areas were also addressed, noting that these do not correspond to large forested zones but rather to patches of native trees that have been gradually reforested, such as *guadua*, a species considered important for soil stability. Among the conservation proposals put forward by this group were reforestation around water sources and springs, protection of stream buffer zones, greywater management to reduce water consumption, and the promotion of reforestation practices in forested areas (see Figure 4a).

The men's group identified areas used for recreation and community activities, such as a chapel, schools, and sports fields. They then focused on demarcating the Piedras River and nearby streams. Afterwards, the group identified water springs and the origins of the streams, followed by forested areas. They also pointed out a native tree reserve and the presence of a nearby wetland, characterized by sinkholes indicating significant underground aquifer recharge. Their conservation proposals included cleaning of the streams, reforestation with native trees, drainage maintenance, promotion of tributary care, planting of native trees and *guadua* near springs, and the prohibition of hunting (see Figure 4b).

The mixed group also recognized recreational areas such as the nursery and sports fields, and began by identifying tributary areas, starting with the Piedras River and the stream. They then located the water springs, emphasizing the properties where the streams originate. Some participants in this group were landowners of properties with water springs, which facilitated their identification. The group then focused on forest patches near the streams. Their conservation proposals included cleaning and reforestation of the stream, drainage maintenance, school workshops to promote tributary care, planting of native trees, the construction of living fences along property boundaries, and reforestation of wetland zones (see Figure 4c).

Co-design of Environmental Zoning in the Timbío River Basin

The environmental zoning of the Brisas aqueduct area is divided into four zones, each with specific characteristics and objectives: a) Strict Preservation Zone, aimed at protecting the Piedras River, its tributaries, forests, and water springs through the establishment of riparian buffers and reforestation with native species; b) Production Zone, encompassing crop cultivation, grazing, and livestock activities, allowed only in areas that do not interfere

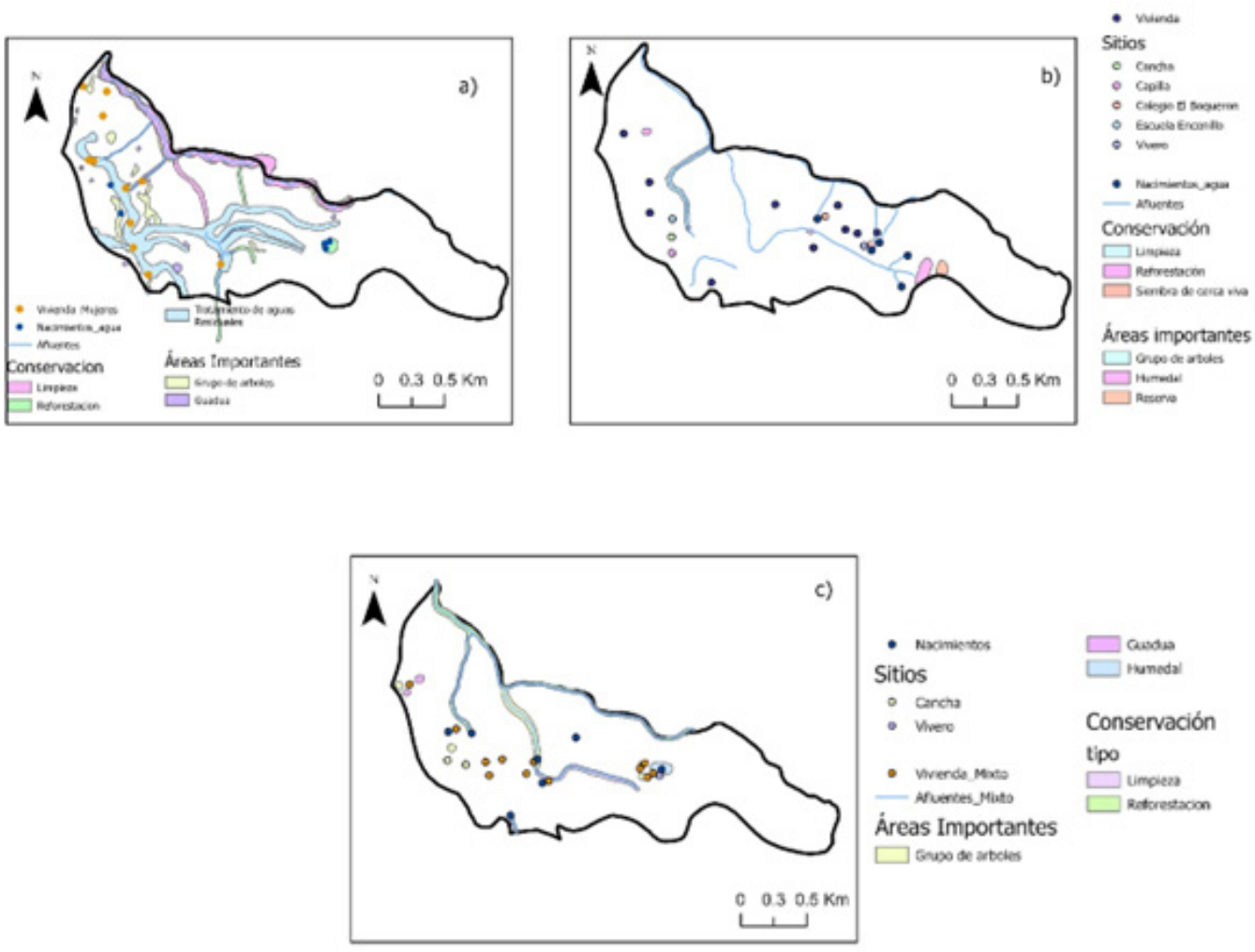

Figure 4. Proposed social mapping of rural aqueduct areas: a) women's group, b) women's group, and c) mixed group.
Source: Author's own elaboration

with other zones and always under sustainable practices; c) Road Corridor Zone, intended to protect the environment along main roads such as the Pan-American Highway, with a 20-meter buffer on each side; and d) Ecotourism, Recreation, and Leisure Zone, designed to promote community well-being, including areas such as sports fields and a plant nursery within the study area (see Figure 5a).

The environmental zoning of the Sachacoco aqueduct area also includes these four zones: a Strict Preservation Zone with 30-meter riparian buffers around the wetland for its protection; a Production Zone subdivided into five land-use categories: urban fabric, crops, crop–natural space combinations, crops and pasture, clean pastures, and natural vegetation areas; a Road Corridor Zone with a 20-meter buffer on each side of the Pan-American Highway, aimed at environmental protection and road safety; and an Ecotourism, Recreation, and Leisure Zone to promote community well-being, with La Chorrera stream as a key feature (see Figure 5b).

Discussion

The evaluation of ecosystem services (ES) in the Timbío River Basin provides a solid framework for environmental characterization and the spatial representation of the benefits ecosystems offer at the local level (Zambrano et al., 2021). The provision of water, one of the most critical ecosystem services in the basin, supports key economic and social activities, with an annual flow reaching 20 million cubic meters—an essential element for both the

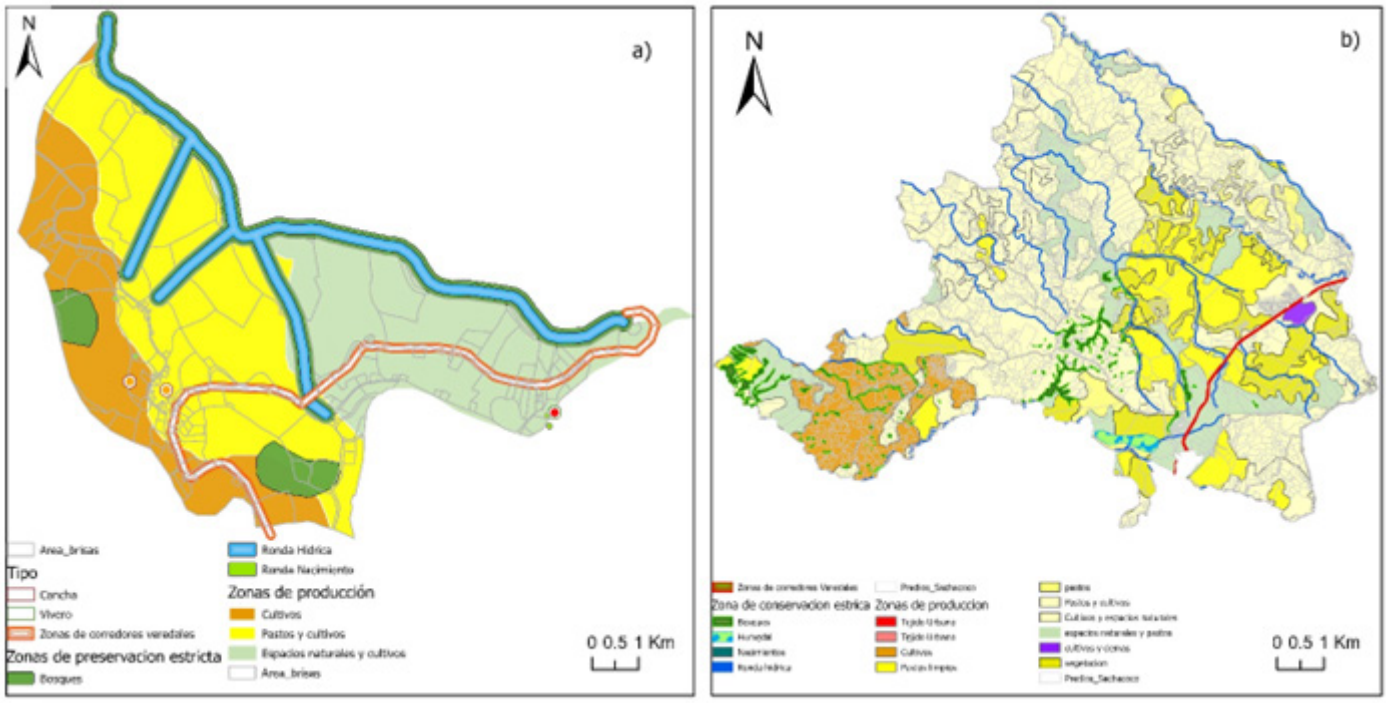

Figure 5. Co-design of the Timbío River basin environmental zoning. a) Brisas Aqueduct, b) Sachacoco Aqueduct.
Source: Author's own elaboration.

hydrological and social dynamics of the study area. Additionally, the carbon storage service highlights the importance of forest cover, as diverse and species-rich vegetation contributes to climate regulation and the mitigation of climate change effects (Zhang et al., 2023).

The nutrient export service serves as an indicator of the health of aquatic ecosystems in the study area. Despite limitations in the model used, mainly due to the lack of comparative data, the results are consistent: higher nutrient concentrations are found near rivers and in areas with dense vegetation, which are associated with increased organic waste and fertile soils. This supports the model's usefulness as a timely tool for evaluating environmental quality (Huamani Cordova, 2020).

Habitat degradation is primarily driven by road infrastructure expansion, urban growth, and mining activities. It is estimated that approximately 45% of the territory shows signs of environmental deterioration, underscoring the urgent need for more rigorous territorial planning and strategic designation of conservation areas to safeguard biodiversity and ecosystem services in the region (Meza Cabrera, 2023).

A crucial component of this environmental zoning proposal is the recognition of the role of women in water stewardship, particularly in the management of rural aqueducts (Mora, 2023). Women's participation is not only vital for water planning but also presents the opportunity to incorporate their experiences and perspectives into the development of water management tools, given their role in accessing and using water. Since the majority of the surveyed population in this study were women, this opens a pathway for developing strategies to promote gender equity by fostering inclusive and empowered actions for the conservation of rural aqueduct zones. The predominance of basic educational levels among women highlights the need to improve access to education and promote continuous training programs that drive community development and educational equity, particularly in water stewardship activities.

The inclusion of women in environmental management not only promotes female leadership but also strengthens gender equity by ensuring that a broader range of knowledge and experiences are integrated into water care and rural aqueduct governance (García Luango, 2020). Community proposals for the creation of water-use scenarios include specific strategies to enhance women's participation in the conservation of water resources, acknowledging that their knowledge can be pivotal for meaningful engagement and the sustainability of conservation efforts (Guevara Gil et al., 2018).

The co-design of environmental zoning scenarios serves as a valuable tool for recognizing local social realities and facilitating informed community-level decision-ma-

king (Ávila Camargo, 2020). Social cartography not only enables inclusive dialogue but also supports more effective placement of community development actions (Moreno-Quintero et al., 2021). In the rural aqueducts of the Timbío River Basin, local participation contributed to a more accurate identification of key conservation areas. Women provided differentiated inputs related to basic services and gender-specific needs, while men focused on identifying infrastructure-related areas and zones for economic activity (Naiga et al., 2024). The integration of results from both groups enables planning that is more aligned with the region's socioeconomic realities, contributing to effective territorial conservation (Castaño-Aguirre et al., 2021).

The zoning proposed in this study presents some limitations, particularly concerning the quality of data used for ES modeling, such as flow rates and land-use changes. Furthermore, there is a need to involve a broader range of water management stakeholders in the study area, including large-scale agricultural producers, producer associations, and environmental authorities, to enhance environmental governance. Addressing these challenges requires strengthening community participation mechanisms and improving the technical capacities of responsible entities through local empowerment.

Conclusion

Rural aqueducts are key socio-ecological systems for the provision and conservation of ecosystem services (ES) in rural areas and play a fundamental role in integrated water management. The co-design of zoning scenarios represents an interdisciplinary approach to environmental management, aiming to recognize the diversity of knowledge and perspectives within the community. Involving women and the broader community in the zoning of ES use enhances the effectiveness and sustainability of conservation measures and promotes gender equity and community empowerment in the development of water management policies.

Women, in their role as water users for both domestic and productive purposes, tend to show greater concern for the efficient use of water, which is reflected in a more conscious care for the benefits provided by ecosystems. This perception was confirmed by local inhabitants of the aqueducts in the study area. However, both men and women have worked hard to conserve the rural aqueduct in the Timbío River Basin, particularly in protecting water resources, as evidenced by the joint efforts of the two aqueducts that are part of the Watershed Corporation of the municipality of Timbío. This community commitment reinforces the importance of continuing to advance in the collective creation and participation in the strategic management of water resources within territorial planning.

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ABREVIATURAS

Ecosystem Services (ES)

Servicios Ecosistémicos (SE)