



Barriers and bridges on water management in rural Mexico: from water-quality monitoring to water management at the community level

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Abstract Access to sufficient water of suitable quality represents a challenge for achieving several dimensions of sustainable development. Currently, water access is restricted to three of 10 persons globally. In rural areas of Mexico and other low-income countries, coverage could be even less due to the absence of formal supply; thus, rural communities usually perform water management. Surrounding community-based water management, various socio-ecological interactions emerge that determine access to water. Access to water will depend on the obstacles or capacities that arise within the socio-ecological

system in which the community is immersed. This work identifies barriers and bridges to water access in a rural environment through mixed methods. The article draws on three case studies in southeastern Mexico by analyzing 90 questionnaires conducted at the household level and three focus groups in parallel with water quality analysis and its relationship with management practices. The barriers and bridges were classified into six water access challenges: (i) access to water in a sufficient quantity, (ii) access to water of adequate quality, (iii) access to water for household crop irrigation, (iv) hygiene and sanitation facilities,

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(v) collective organization, and (vi) climate variability. The main findings indicate that households' water quantity and quality show deficiencies due to the lack of formal infrastructure and represent a health risk. Water fetching has the highest impact on women and children in poor rural areas, and it is a significant barrier to sustainable development. In contrast, the collective organization proved to be an essential bridge for water access in these communities.

Keywords Community-based · Water management · Collective organization · Rural communities · Water quality

Introduction

Access to water is essential to promote sustainable development and human well-being. In 2010, the United Nations General Assembly explicitly recognized access to water as a human right, establishing that access to drinking water and sanitation is crucial for developing a dignified life, which is established within the Sustainable Development Goal 6 (SDG 6) (UN-Water, 2015). According to the World Health Organization (WHO), water access must be sufficient and continuous for personal and domestic use, including water for drinking, personal sanitation, food preparation, and house cleaning. This organization has established that between 50 and 100 L of water *per person per day* are necessary to satisfy an individual's basic needs (WHO, 2003). Nowadays, three of 10 persons do not have this amount of water in their homes, and this could increase due to various factors, including inadequate resource management by the formal and informal institutions involved (UN-Water, 2015).

Water management remains a significant challenge worldwide, particularly in rural areas, exacerbated by a lack of formal network pipes or infrastructure. In Mexico, about 10% of the population does not have access to water, and of those who do, 30% do not receive water continuously or of acceptable quality (Perló, 2019). The municipalities oversee providing water and sanitation services to the population; however, they only partially complied with this. The government's absence and non-compliance with basic services drive communities to manage resources independently, promoting different strategies not

considered within formal policies (COMDA, 2017). Water management tends to be community-based, whereby access to water in quantity and quality is not always guaranteed (Cavender-Bares et al., 2015; Elliott et al., 2019). Therefore, access to water will depend on the capacity of a community to face obstacles and unexpected changes (Gunderson et al., 1995; Pahl-Wostl et al., 2010).

In Mexican territory, renewable water, which can be used annually in a region, is naturally distributed in a heterogeneous manner since in the southeast of the country, renewable water is seven times greater than in the center and north, where the largest population is concentrated (CONAGUA, 2018). However, in Southeast Mexico, particularly in Chiapas, 56% of individuals do not have basic water services (CONEVAL, 2020), despite being the most important hydrological region in the country. Many families do not have continuous access to water, and toilets generally comprise latrines for shared use. One example is the Río Grande de Comitán-Lagos de Montebello (RGC-LM) watershed, in which water supply coverage is significantly lower and more limited than in urban areas. The RGC-LM watershed is located in the Grijalva-Usumacinta region, Mexico's most important hydrological region with the most significant amount of renewable water *per capita* (Sánchez et al., 2015).

From how water users relate with each other and with different components of the ecosystem, a variety of social and environmental interactions emerge, which can determine access to water through the decision-making process (Bodin & Crona, 2009; Bodin et al., 2006). In this study, water management actions were categorized as barriers and bridges, which change across scales. The barriers and bridges are the actions, individual or collective, that arise from the decision-making process around community-based water management, and they can improve or inhibit access to water in terms of quantity or quality. For instance, practices surrounding access to and storage of water, community agreements for the use of water, and activities around traditions or rituals, among others, can represent barriers and bridges to access to water of suitable quantity and quality. It is well known that poverty, inequality, and climate change, to mention a few examples, inherently condition the emergence of barriers and bridges and therefore individual and collective's access to water. These large-scale processes can

influence the dynamics of socio-ecological systems (Folke, 2006; Ostrom, 2009) and can function as barriers to access to natural resources. However, practices on the local scale are critical if one seeks to generate longer-term changes.

Identifying local barriers and bridges could be the first step to achieving results that improve the conditions of access to water, in addition to aiding communication between users and decision-makers in the development of water management strategies oriented toward sustainability (Cavender-Bares et al., 2015). Challenges continue to be faced regarding access to water because the complex interactions of users with water sources are not considered. In addition, the capacity for change within water management, barriers, and bridges is unknown (Pahl-Wostl et al., 2010). In this regard, it is crucial to identify what determines water management dynamics, what the barriers are, and what the bridges are in a local context (Pahl-Wostl & Kranz, 2010).

This study aims to understand community-based water management by identifying barriers and bridges around access to water from the individual to the collective scale in a rural context. Therefore, we focused on answering the following: (i) What are the current practices surrounding water use and management at the household and community level? (ii) What is the relationship between water quantity and the quality of available water and management practices? (iii) What are the main barriers and bridges faced by the communities regarding access to water? The article draws on three case studies within the RGC-LM watershed, which were analyzed using mixed methods to have an inclusive perspective and integrate processes at different scales.

Case study

This study was conducted in Chiapas, specifically at the Río Grande de Comitán-Lagos de Montebello (RGC-LM) watershed, close to the Guatemala border. The watershed covers an area of 754 km² and is located within three municipalities: Comitán de Domínguez, La Trinitaria, and La Independencia. The RGC-LM watershed is within the Grijalva-Usumacinta Hydrological Region (INEGI, 2010), a region considered the main renewable water reserve (Sánchez et al., 2015). Located within this watershed

is the Natural Protected Area “*Parque Nacional Lagunas de Montebello*,” an area with 52 lakes of karst origin, which has been declared a Priority Land Area for Conservation (CONANP, 2007) and a Ramsar site since 2003 (Fig. 1). This hydrological system is considered a vulnerable water area (Alvarado et al., 2022) due to multiple socio-economic pressures over the last three decades (Alcocer et al., 2018, 2021). The lack of adequate sewage systems, wastewater treatment plants, and the expansion of urban and agricultural areas have caused the degradation of water resources (Alcocer et al., 2018; Alvarado et al., 2022). These impacts are unfavorable because, in the basin, 194,247 inhabitants receive water for human use and consumption (INEGI, 2020), and their livelihoods are tied to the lacustrine system.

For the development of this study, we selected three communities, including Juznajib, El Triunfo, and Tzisco, as case studies, which have inadequate or no water supply services, lack drainage, and water management is carried out by community members through committees. These communities were selected to include different water management practices and ecological conditions within the basin, applying the following criteria: (i) by the representativeness of the upper basin, middle basin, and lacustrine system; (ii) by water supply type; (iii) by soil conservation practices; and (iv) based on economic activities (Table 1).

Methods and analysis

Water management at the household level

For this work, we used a mixed-method approach, which was applied to three communities in the RGC-LM basin. The study of resource management and its governance requires quantitative information and qualitative analysis because different types of knowledge are involved that need to be integrated into an inclusive framework capable of incorporating processes at different temporal and spatial scales (Pahl-Wostl & Kranz, 2010).

We applied a questionnaire to 90 households in the three communities, 30 per community, between 2019 and 2020. We conducted convenience sampling (Patton, 1990), and saturation of responses was achieved in each community (Martínez-Salgado, 2012; Morse, 1995). The design of the questionnaire

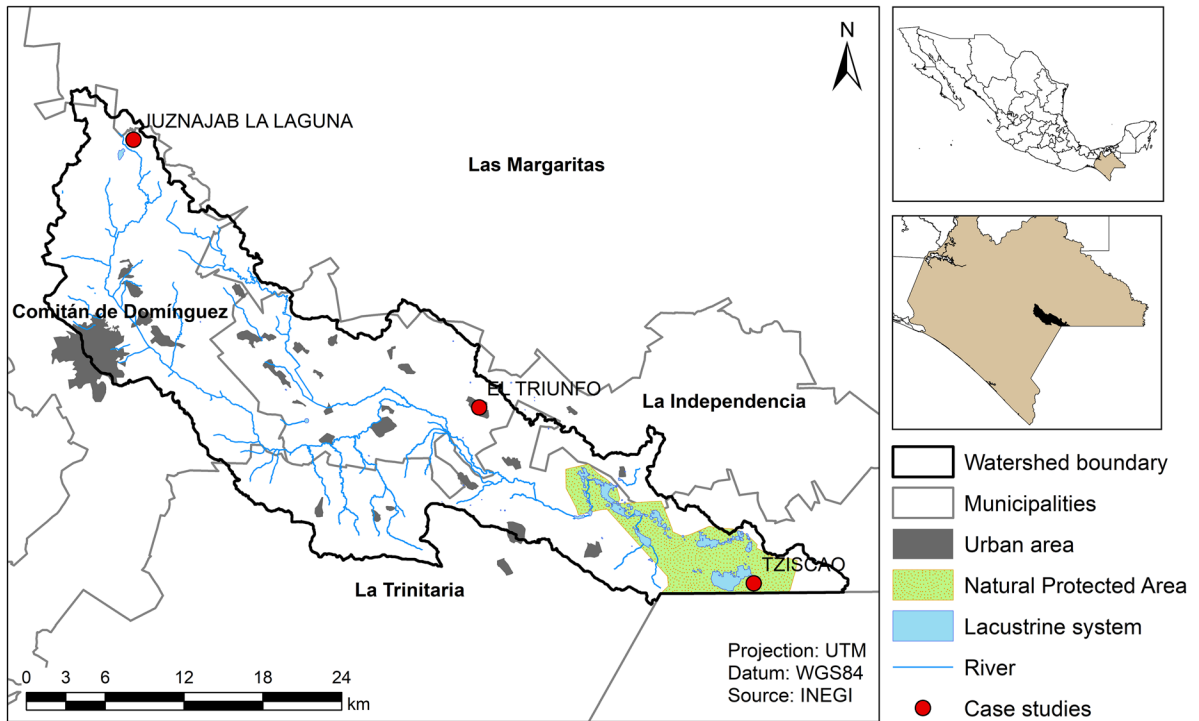


Fig. 1 This map shows, in red dots, the locations of the case studies within the Río Grande de Comitán-Lagos de Montebello watershed. Juznajab in the upper basin, El Triunfo in the

middle basin, and Tziscoao as the lacustrine system in the lower basin, located within the Natural Protected Area

was based on previous water access research (OMS & OPS, 2009; Bartram et al., 2014; UN-Water, 2015), which included the following five sections: (i) sociodemographic indicators, (ii) accessibility to water, (iii) water practices and uses, (iv) community agreements and rules, and (v) hygiene and sanitation practices. The instrument contained closed and open questions, allowing an analysis of the codification of management practices, water access conditions, water quality, and health issues. The data were captured

in a database in excel and analyzed with descriptive statistics with the R version 4.0.3 statistical software program.

Water management at the community level

We conducted a focus group (Taylor & Bodgan, 1984) to obtain a collective perspective on community-based water management in each community, in which men and women of legal age (> 18 years) participated.

Table 1 Demographic characteristics and water access condition in three communities of RGC-LM watershed, Chiapas, Mexico (INEGI, 2020)

Community	Basin location	Total population	Inhabited houses	% Homes without water service	Water source	Land conservation	Main economic activity
Juznajab	Upper basin	840	172	9.3	Lake	Community agreement	Rainfed agriculture
El Triunfo	Middle basin	5660	1290	1	Well	None	Irrigated agriculture
Tziscoao	Lacustrine system	1939	344	100	Lake and river	Federal decree	Tourist activities, rainfed agriculture

The conversation was guided through pre-established questions, while attendees were asked to draw on a flip chart. This method was performed through participatory mapping (Brouwer & Brouwers, 2016; Pathways Network, 2018), facilitating conversations on water management in the community. Different social actors attended each focus group, men and women, including water users at the household scale, water users at the parcel scale, water managers as members of the surveillance committees, and community authorities voluntarily. Participants made a map of the community as a group while describing the different water management practices, community agreements, and norms and identifying capacities and obstacles to access the resource individually and collectively. During the process, transcripts were made of the collective dialog that emerged around water management in the community.

Water-quality monitoring

In the three communities, we analyzed household water samples to link management practices with water quality from different water sources (lake, river, well, rainwater, and bottled water). The following physicochemical indicators were measured from the samples obtained: temperature ($^{\circ}\text{C}$), pH, dissolved oxygen (DO) (mg/L), electrical conductivity ($\mu\text{S}/\text{cm}$), total dissolved solids (TDS) (mg/L), turbidity (NTU), ammonia nitrogen (N-NH_4^+), and nitrates (NO_3^-), using a YSI EX02 (Yellow Springs, OH) multiparameter water-quality probe. Residual chlorine in the water was measured using the Spectrophotometer model DR 2800 (Loveland CO). Additionally, we measured microbiological indicators in household samples with Petrifilm 3 M plates for total coliforms and *Escherichia coli*. The results were collected in a database for their statistical description and evaluated by Mexican Standard NOM-127-SSA-1994, which establishes permissible water limits for human use and consumption (DOF, 2000).

Subsequently, we performed a principal component analysis (PCA) to describe the relationship between water quality with community management practices. We used PCA to reduce the number of variables about water quality into a smaller number of variables, or components, which describe the results in a simpler way (conductivity, turbidity, *E. coli*, etc.). This allowed us to relate the components found

with the management strategies (rainwater harvesting, water fetching, etc.). We used physicochemical and microbiological parameters as quantitative variables, and as qualitative variables, practices for access to water (water service inside the household, water service inside the property, rainwater harvesting, and water fetching). All analyses were performed with R version 4.0.3 statistical program software.

Identification of barriers and bridges

To reach the main objective of this work, we identify barriers and bridges through the coding and classification of questionnaires, water monitoring, and the results of the focus groups. As described previously, barriers and bridges in this study are defined as actions, individual or collective, that arise from the decision-making process around community-based water management. They can improve or inhibit access to water in terms of quantity or quality. The barriers and bridges were also categorized as individual and collective, based on the multilevel action situation proposed by Barnes et al. (2017). The individual level consists of obtaining water at home, where decisions regulate daily activities. The collective level is based on collective-choice rules, collaborative efforts, community agreements, or norms; at this level, decisions can affect or benefit several families and impose sanctions when they are not achieved. Barriers and bridges, both individual and collective, were grouped in turn in the following six water access challenges: (i) access to water in a sufficient quantity, (ii) access to water of adequate quality, (iii) access to water for household crop irrigation, (iv) hygiene and sanitation facilities, (v) collective organization (agreements and norms), and (vi) climate variability. The challenges (i), (ii), (iv), (v), and (vi) were chosen since those are considered objectives or indicators within the Sustainable Development Goals (SDGs) specifically on SDG 6 (UN-Water, 2015), as well as recommendations by the World Health Organization for access to water and sanitation (WHO, 2003). These frameworks make it possible to compare discussions that are taking place in other contexts or regions of the world. Challenge (iii) was incorporated after interviews with the local inhabitants since part of their livelihoods is self-consumption agriculture in the backyard. The SDGs address issues of marginalization, vulnerability, and inequity. However, it is important to consider

that it is a global framework, which can leave aside local contexts (Fukuda-Parr, 2017).

Results

Community context

From the questionnaire applied, 100% of the respondents were women because they represented the leading water managers in their homes and were willing to respond to the interview. It is important to highlight that women manage water at the household level, however, in decision-making at the community level, women have little participation. The age of respondents ranged from 22 to 74 years; 43% had incomplete primary school studies, 22% had completed primary school, 20% had finished high school, 7% had no studies, and only 1% had a bachelor's degree. The main occupation was housewives with 89%, business or sales with 8%, farmers with 2%, and students with 1%. Monthly income ranges from USD 10 to USD 400 per month. Juznajab had the lowest average income with USD 75, Tziscoo with USD 90, and El Triunfo with an average of USD 190 per month.

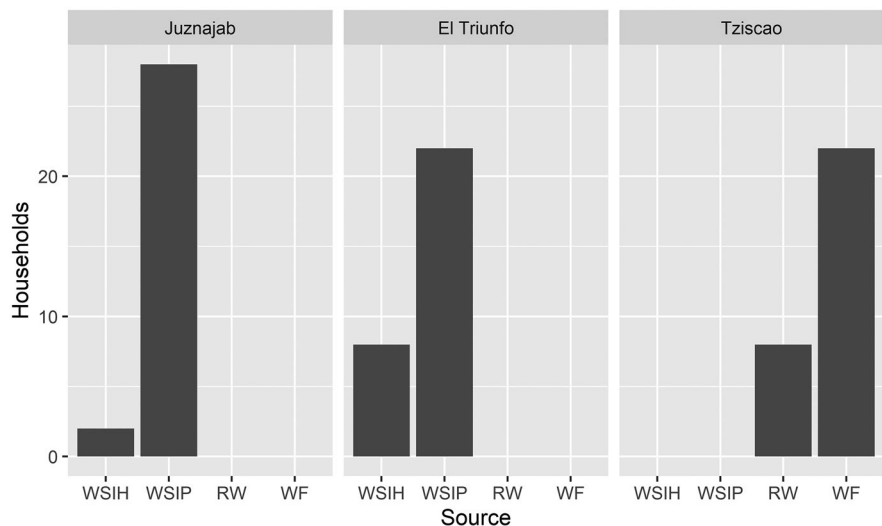
In these communities, land tenure is carried out through *ejidos*. An *ejido* is a portion of land for shared use, mainly destined for agriculture and forest and water use (DOF, 1992). Management is carried out under the agreements of an *Asamblea Ejidal*

(assembly), in which the *Comisariado Ejidal* (commissary) and the *Comité de Vigilancia* (surveillance committee) participate. The *Asamblea* is where the decision-making process takes place, and it has the objective of the orderly management of community life and the productive and economic aspects. Water, forest, agriculture, and tourism regulation committees may arise from this *Asamblea*. Decision-making within the *Asamblea* is solely made by men.

Water access

Access to water for human use and consumption in these communities can differ regarding the available infrastructure and the primary supply source. For Juznajab, access to water is by water pumping, whose pipes were installed by the municipality in the 1990s and abandoned in the hands of the community. In Juznajab, 90% of families have water service inside the property, and 10% have water service inside the house (Fig. 2). Juznajab currently manages water, forest, and agricultural activities through community agreements. Water management is organized by a committee that collects fees (USD 0.25 per person per month) for pumping water, maintaining, and repairing pipes, and implementing actions to care for land and water. When these actions or agreements are not fulfilled, monetary fines are applied. In recent years, Juznajab received water only 3–5 h per day due to insufficient pumping and pipelines.

Fig. 2 Frequency of the primary water source for human use and consumption in three communities of the RGC-LM, Chiapas. Answers from a semi-structured interview (2019 and 2020). WSIH: water service inside the house; WSIP: water service inside the property; RW: rainwater harvesting; WF: water fetching



El Triunfo, located in the middle basin, has intensive agriculture activity. In this community, water is supplied through a well, in which 77% of the homes have water service inside the property, and 23% have water service inside the house (Fig. 2). The community handles pumping and water chlorination without any fee, and water scarcity is mainly due to the location of the household. Due to low pump pressure, homes on steep slopes do not receive sufficient water.

Despite being located within a Protected Natural Area and a lacustrine system, the community of Tziscaco lacks a formal water service. Locals noted that they had made demands on the municipal government, but they still have received no response. Therefore, access to water is mainly via water fetching from the lake or the river and rainwater harvesting (Fig. 2). Another way to get water is to purchase water tanks (1000 L) from the river, the cost of these ranging between USD 5 and USD 7.5 each. In Tziscaco, the interviewees mentioned that water scarcity in households is mainly due to low storage capacity and the scarcity of rain. On the other hand, we registered that bottled water represents the main water supply

for drinking and cooking in 73% of households in the three communities.

Collective organization and community agreements

As already mentioned, the *Asamblea Ejidal* represents the decision-making process for water and land management in these communities. Proposals are put to the vote and are accepted if the majority agrees. Those attending the *Asamblea* are male farmers, and a woman can participate if she is a widow or sole heir to an *ejido*.

To evaluate the collective organization in water management, we addressed aspects involving community agreements, community cooperation, and actions to improve access to water. Based on the interviews, most respondents, between 100 and 83%, mentioned community agreements for water management in the three communities (Fig. 3). The main actions carried out in Juznajab and El Triunfo are related to water quantity, specifically to avoiding the excessive use of water. Concerning water use for agricultural activities, in Juznajab, household

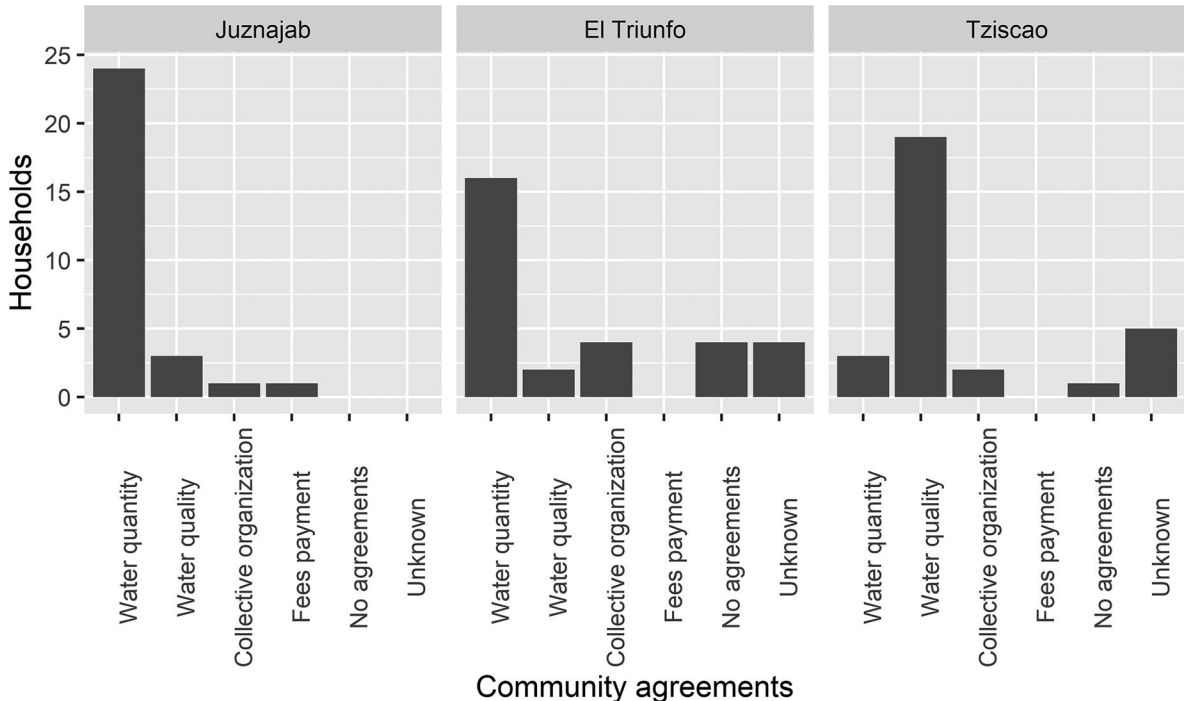


Fig. 3 Types of community agreements around water management in three communities of the RGC-LM, Chiapas. Answers were obtained through a semi-structured interview (2019 and 2020)

crop irrigation is restricted in the dry season, limiting vegetable cultivation and potentially affecting the family's diet. Water-quality care was mentioned most in Tzisco, referring to the need for chlorination and preventing the use of soaps and agrochemicals near water bodies. Some people mentioned the creation of water management committees within the collective organization agreements. The payment of community fees was another agreement, and other respondents mentioned that there were no agreements, or if there were, they did not know about it.

In terms of improving access to water, answers were focused on the need for a water supply system. In Tzisco, 63% of the respondents consider it necessary to have water inside the house through external support, either from the government or civil associations. In contrast, responders from Juznajib and Tzisco who have water services consider it necessary not to waste water or use less water. Under this heading, adaptive actions to improve water access at the household level in the three communities are related to the quantity of water: 55% refer to reducing their water use and storing more water.

Hygiene and sanitation habits

The lack of adequate water supply service in the three communities studied makes it essential to verify water disinfection practices for human use and consumption. Only 37% of the households disinfect water for drinking. Boiling water is the most widely used method in the three communities, a practice that can imply firewood harvest and consumption. On the other hand, fewer than 50% of households in Juznajib and Tzisco have a facility for washing their hands with water and soap, compared to 77% in El Triunfo. Regarding wastewater disposal, between 77 and 90% of the families use this for household crop irrigation in the three communities. Sewage disposal is performed through septic tanks in 80% of the homes due to the absence of a drainage system and a wastewater treatment plant facility.

Health and water sources

Health is a crucial factor affected by the absence of continuous and safe water. In the communities studied, 22% of those surveyed claimed to have had a

gastrointestinal problem in the last year, but only 7% associated it with the drinking water, among which four inhabitants were in Juznajib and three in El Triunfo. The same interviewees perceive supply water sources as dirty or contaminated.

Regarding health services, 88% of those interviewed mentioned having a public-health service, 90% in Juznajib, 37% in El Triunfo, and 100% in Tzisco. Nevertheless, the service is considered deficient because physicians are rarely found in the clinics, and medicines are in short supply in the three communities. In this case, seeking care at private medical services is inaccessible for most persons, and only one person mentioned having access to a private medical service in El Triunfo.

Water quality and management practices

A total of 153 household water samples in Juznajib, El Triunfo, and Tzisco were obtained from different supply sources during 2019 and 2020. Table 2 shows the results of the three communities. The pH values were mainly homogeneous and around 8, all within the permissible limits of the Mexican Standard (6.5–8.5). The conductivity values are suitable according to WHO (2006) (<2500 $\mu\text{S}/\text{cm}$); we employed recommendations of this organization since the Mexican regulations do not consider this parameter. Turbidity values fell within the permissible limit of the Mexican Standard (5 NTU), although we found some atypical values above this limit in the different sources.

Free chlorine was measured to corroborate disinfection in supply sources. El Triunfo was the only community that complies with the recommended by Mexican regulations (0.2–1.50 mg/L). The remainder does not use chlorination as a disinfection method. Although the mean values of ammonia were found below the permissible limit (0.5 mg/L) by Mexican regulations, there are high values recorded in some samples in Tzisco, with high concentrations of ammonia in water indicating possible sewage or animal waste contamination. Likewise, the nitrate concentrations reported fell below the limit of 10 mg/L established by the Mexican standard. Nevertheless, some water samples in El Triunfo and Tzisco presented higher concentrations. Nitrate is used mainly in inorganic fertilizers, and its presence in

Table 2 Physicochemical and microbiological parameters of water quality in three rural communities in Chiapas, Mexico

Community	n	Metric	pH	Conductivity (µS/cm)	Turbidity (NTU)	Free chlorine (mg/L)	NH ₄ ⁺ (mg/L)	NO ₃ ⁻ (mg/L)	Total coliforms (CFU/100 mL)	<i>E. coli</i> (CFU/100 mL)
Juznajib	Median		8.16	438.2	1.06	0.03	0.17	0.56	0	0
	SD		0.11	53.54	1.29	0.01	0.10	0.38	244.4	0
	Min/max		7.82/8.28	372.2/590.1	0/5.82	0/0.04	0.02/0.44	0.2/1.81	0/1 100	0/0
El Triunfo	Median		7.53	735	0.06	0.25	0.45	3	0	0
	SD		0.47	218.67	0.94	0.15	0.12	9.73	1397.5	0
	Min/max		6.62/8.46	72.7/981.2	0/6.4	0/0.65	0.01/0.35	0/31.91	0/8 200	0/0
Tziscoao	Median		7.94	296.9	0.77	0.01	0.03	1	600	0
	SD		0.38	147.99	1.67	0.01	0.38	5.07	1882.32	185.79
	Min/max		5.84/8.96	8/777.8	0.02/7.81	0/0.03	0.01/2.34	0.12/31.58	0/10 000	0/1 000

groundwater and surface water is usually low. Nonetheless, it can reach high levels because of leaching or runoff from agricultural land or human or animal waste contamination.

Mexican regulations establish 2 CFU/100 mL as a permissible limit for total coliforms. Since this does not refer to the concentration of *E. coli*, it was evaluated by WHO (2006), which establishes 0 CFU/100 mL as a safe water goal, whose presence is considered evidence of recent fecal contamination. The presence of total coliforms was generally low in Juznajib and El Triunfo, and in Tziscoao, it was higher, with a median of 600 CFU/100 mL. We registered an absence of *E. coli* in Juznajib and El Triunfo; otherwise, in Tziscoao, there was 1000 CFU/100 mL.

The results of household water quality were calculated according to the supply source type (Table 3), which corresponds to bottled water, lake, rainwater, river, and well samples. We consider it relevant to show this because the water source can determine its quality and influence management practices. Therefore, we will discuss only those that stand out.

The conductivity values were heterogeneous for the different supply sources. Rainwater samples had the lowest mean value of 22.3 µS/cm, well water samples had the highest value of 735 µS/cm, and bottled water showed a more significant rank in the records. The means of the turbidity values fell within the permissible limit of the Mexican Standard (5 NTU), having some maximum values above this parameter in the different sources. Well water was the only source that complied with free chlorine concentrations by Mexican regulations (0.2–1.50 mg/L) and some bottled water samples. Bottled water samples showed the highest concentrations registered regarding ammonium and nitrate concentrations.

Total coliforms were mainly detected in rainwater and river water, with a median of 850 CFU/100 mL and 1600 CFU/100 mL, respectively. Although *E. coli* concentrations are significantly lower than total coliforms, they are still high for human consumption. The highest record was in rainwater and river water, with a 50 CFU/100 mL median, followed by the maximum value in bottled water. The presence of bacteria in bottled water is worrisome because it is usually consumed directly without any previous disinfection treatment.

The PCA results are described in two principal components, of which 53% of the variance is

Table 3 Physicochemical and microbiological parameters from different water supply sources, collected in households in Chiapas, Mexico

Water source	n	Metric	pH	Conductivity (µS/cm)	Turbidity (NTU)	Free chlorine (mg/L)	NH ₄ -N (mg/L)	NO ₃ ⁻ (mg/L)	Total coliforms (CFU/100 mL)	<i>E. coli</i> (CFU/100 mL)
Bottled	Median	7.89	317.4	0.2	0.025	0.17	1.74	0	0	
	SD	0.22	253.69	1.34	0.14	0.38	10.46	1521.04	31.96	
Lake	Min/max	7.52/8.46	72.7/981.2	0/6.97	0/0.54	0.01/2.34	0/31.91	0/8 200	0/200	
	Median	8.16	433.5	0.62	0.03	0.15	0.56	0	0	
Rainwater harvest	SD	0.10	63.25	1.29	0.01	0.10	0.32	243.24	0	
	Min/max	7.82/8.28	265/590	0/5.82	0/0.04	0.02/0.44	0.2/1.6	0/1 100	0/0	
River	Median	8.11	22.3	0.57	0.01	0.02	0.58	850	50	
	SD	0.64	113.91	2.08	0.01	0.08	0.55	2645.72	112.36	
Well	Min/max	5.84/8.96	8/472.6	0.09/7.81	0/0.03	0.01/0.28	0.12/2.25	0/10 000	0/300	
	Median	7.94	298	0.76	0.01	0.03	1	1600	50	
River	SD	0.24	126.19	1.23	0.01	0.06	3.58	1694.4	309.84	
	Min/max	7.7/8.78	10.3/375.7	0.05/4.1	0/0.03	0.01/0.21	0.43/14.14	100/6 000	0/1 000	
Well	Median	7.16	735.1	0.17	0.37	0.01	1.17	0	0	
	SD	0.25	66.92	1.26	0.14	0.03	4.67	787.7	0	
Well	Min/max	6.62/7.85	544.3/922.2	0/6.4	0.06/0.65	0.01/0.19	0/12.21	0/4 000	0/0	

explained. We used a scree-plot criterion to select the principal components, of which three had an eigenvalue equal to 1. However, employing three principal components might not be the best way to visualize the data. The PCA analysis aimed to enhance the discussion concerning the relationship of water quality with management practices in the studied communities. We analyzed the results according to water access practices. Four different types were identified: rainwater harvesting, water fetching, water inside the house, and water inside the property (Fig. 4). The two water groups inside or outside the household did not show substantial differences in chlorine concentrations, conductivity, and pH, corresponding to groundwater characteristics in karstic environments and disinfection practices. Rainwater harvesting is related to nitrates and total coliforms. Water fetching presented a variation in water quality related to ammonia, microbiological indicators, and turbidity; this practice is related to the lowest water quality. Water fetching is present in Juznajab, where there is a lack of water infrastructure, which puts the water quality at risk when it is transported and stored.

Barriers and bridges around water access

The results of this analysis arise from the differences in water access and management among the three communities (Table 4). We present barriers and bridges, individual and collective, in the columns and six main challenges around water management in rows. This table summarizes the most outstanding results of the different methods that we applied. Based on water quality results (Tables 2 and 3), we infer the barriers and bridges as qualitative indicators. This interpretation is the base of Table 4. For example, the presence of coliform bacteria and *Escherichia coli* and low concentrations of free chlorine at a community level (Table 2) were related to the lack of a disinfection method mentioned in the interviews.

For access to water in sufficient quantity for human use and consumption, Tziscoa is the community that faces the most significant barriers due to its need for water fetching, which implies a higher economic expense and investment of time. Lack of knowledge about disinfection methods represents a risk to health, which has been diminished by certain practices such as boiling water.

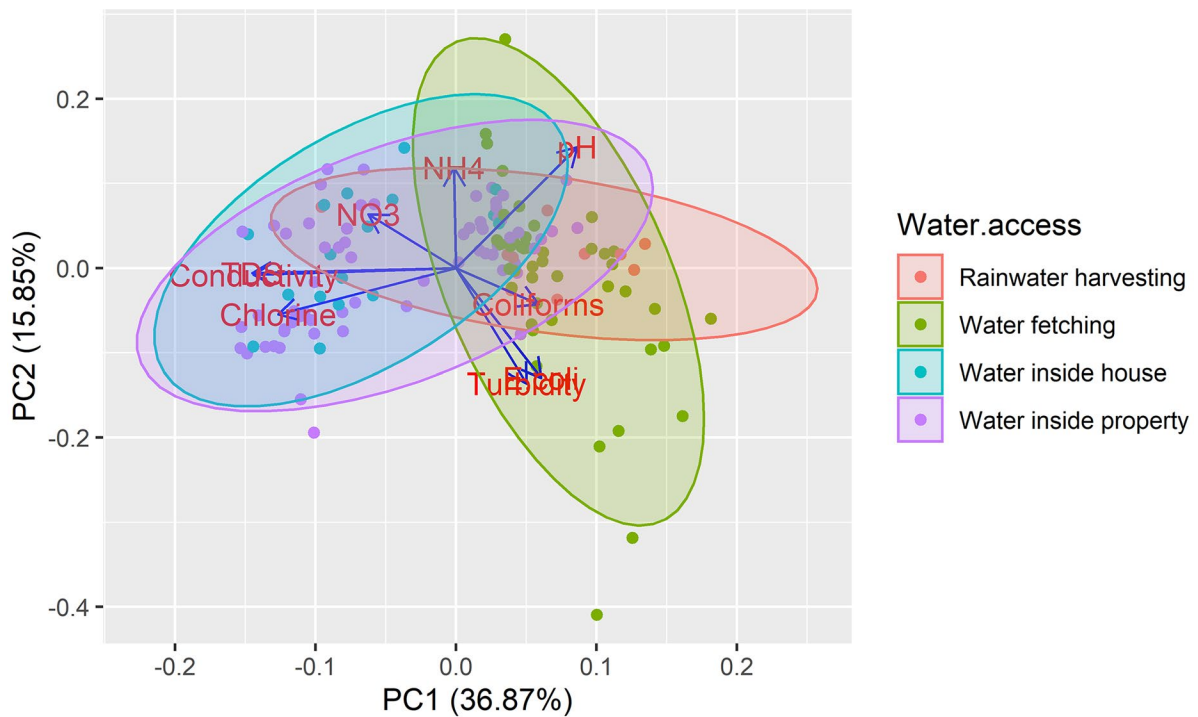


Fig. 4 Principal component analysis of water-quality parameters by type of water access in households

Table 4 Barriers and bridges around community-based water management in rural communities of the RGC-LM watershed, Chiapas

Community	Barriers		Bridges	
	Individual	Collective	Individual	Collective
I. Access to water in sufficient quantity				
Juznajib	Households on steep slopes or far from the supply source Low storage capacity	Deficient maintenance of water pumping	Installation of water storage tanks	Payment of community fees for maintenance and repairing
El Triunfo	Households on steep slopes or far from the supply source	Deficient maintenance of water pumping	Installation of water storage tanks	
Tziscaco	Low storage capacity Low income for buying bottled water	Lack of a water supply service Sale of water tanks informally	Rainwater harvesting	Construction of community water tanks
II. Access to water of adequate quality				
Juznajib	Low use of disinfection methods	Lack of knowledge and monitoring of water quality	Boiling water as a disinfection method	Restricted activities near the lake
El Triunfo	Low use of disinfection methods	Lack of knowledge and monitoring of water quality	Boiling and chlorination as a disinfection method	Well disinfection practices
Tziscaco	Water fetching and storage for a long period Lack of use of disinfection methods	Low maintenance of community water tanks	Boiling water as a disinfection method	
III. Access to water for household crop irrigation				
Juznajib	Inadequate quantity and quality of irrigation	Irrigation restriction in the dry season	Sowing rainfed crops	Agreements to plant rainfed crops
El Triunfo	Inadequate quantity and quality of irrigation	Lack of adoption of low-consumption irrigation systems	Sowing rainfed crops	
Tziscaco	Inadequate quantity and quality of irrigation		Rainwater harvesting for irrigation Sowing rainfed crops	Rain most of the year
IV. Hygiene and sanitation facilities				
Juznajib	Lack of adequate facilities for personal and household hygiene	Lack of sewage and medical services	Recognition of the hand-washing importance	Replacement of latrines with toilets
El Triunfo	Lack of adequate facilities for personal and household hygiene	Lack of sewage and medical services	Recognition of the hand-washing importance	Replacement of latrines with toilets
Tziscaco	Lack of adequate facilities for personal and household hygiene	Lack of sewage and medical services	Recognition of the hand-washing importance	Replacement of latrines with toilets
V. Collective organization				
Juznajib	Disinterest or ignorance of community agreements	Restrict the participation of women	Be aware of community agreements about water quantity	Water management and vigilance committee Payment of community fees Community-based forest management

Table 4 (continued)

Community	Barriers		Bridges	
	Individual	Collective	Individual	Collective
El Triunfo	Disinterest or ignorance of community agreements	Restrict the participation of women	Be aware of community agreements about water quantity	Water management committee
Tziscoa	Disinterest or ignorance of community agreements	Restrict the participation of women	Be aware of community agreements about water quality	Water management committee Tourism and conservation committees
VI. Climate variability				
Juznajib	Uncertainty about rain variability	Community agreements based on rain uncertainty	Postponement of rainfed planting	Agreements about water care in the dry season Reforestation plans
El Triunfo	Uncertainty about rain variability	Decisions based on the uncertainty of the rainy season	Postponement of rainfed planting	Access to groundwater
Tziscoa	Uncertainty about rain variability	Decisions based on the uncertainty of the rainy season	Postponement of rainfed planting	Federal conservation agreements

Most families have a small crop inside their household, where vegetables and maize are irrigated with wastewater of inadequate quality because there is no drainage system, and irrigation is prohibited in the dry season. The lack of facilities for hygiene and sanitation represents individual and collective barriers. In recent years, the replacement of latrines with toilets has been promoted in these communities. However, sharing a facility to wash dishes, clothes, and hands represents a health risk, considering that clothing can contain agrochemicals and pathogens.

The main barriers to the collective organization are disinterest or ignorance about community agreements and the exclusion of some stakeholders from decision-making during the *Asamblea*, principally excluding women. However, most residents know about and carry out community agreements for water care and soil management, promoting bridges for safe access to water. Creating committees has also made it possible to monitor and maintain these agreements.

The last challenge for water access is climate variability, a complex phenomenon in which we only address the aspects of rainfall variation mentioned in interviews. Uncertainty concerning the rainy season represents a barrier that affects individual and collective decision-making, such as sowing and rainwater harvesting. On the other hand, individuals have acted in terms of water care, especially during the

dry season, and they have implemented reforestation plans to promote the frequency of rain.

Discussion

Water management context

In rural areas of Mexico and other low-income countries, community-based rules or agreements are the usual way of managing water. However, access to water in quantity and quality is not always guaranteed (Cavender-Bares et al., 2015; COMDA, 2017; Zamudio, 2020). It has been suggested that community-based management may also positively affect the capacity for the development and empowerment of communities to manage their resources (Agarwal & Narain, 1999; Kearney et al., 2007; Zamudio, 2020). Community-based management arises from the interaction of stakeholders with the ecosystem through decision-making, which can limit or favor access to water on an individual or collective level (Alexander et al., 2016; Barranco, 2020). We identify this duality as barriers and bridges, which can hinder or impede access to water or create a window of opportunity to improve community-based management.

We analyzed three case studies in the RGC-LM watershed in the present study. Despite their being in

the same basin, their inhabitants approach solution strategies for access to water differently. The main results showed that the studied communities do not have sufficient access to water in quantity and quality. In Juznajab and El Triunfo, the household water service could be considered *basic*, while in Tzisco, it is *limited* or *unimproved* according to WHO (2017), which criteria on accessibility, availability, and quality of drinking water services are included.

Water quantity and quality

To address the lack of water for human use and consumption, whether individually or collectively, storage capacity was the main bridge mentioned in the three case studies. However, water storage becomes a difficult task when it is necessary to go to the sources, as in the case of Tizaco. The absence of infrastructure for water supply is the main barrier to accessing an adequate amount of water for the members of a family.

The water-quality monitoring provided evidence of fecal contamination in the three communities; Tzisco had the highest records of up to 10,000 CFU/100 mL of total coliforms and 1000 CFU/100 mL of *E. coli*. This situation could be related to management practices at the household level, such as water fetching and long storage time, which propitiate conditions for the proliferation of microorganisms (Falkenberg et al., 2018; Vázquez-Salvador et al., 2020). The remainder of the parameters is generally adequate conditions for human consumption according to Mexican Regulations (DOF, 2000), with some exceptions for nitrogenous nutrients. Bottled water presented the worst conditions compared to other water sources, which is of concern because bottled water is consumed without any disinfection treatment. Communities have implemented the boiling of water from natural sources to avoid purchasing bottled water, a significant economic expense for marginalized communities. On the other hand, the lack of adequate facilities for personal and household hygiene represents a barrier to sanitation, which is part of Goal 6 of Sustainable Development (UN-Water, 2015). Hand-washing and hygiene practices can mitigate waterborne diseases (Falkenberg et al., 2018), which is crucial, especially with exposure to COVID-19.

A common practice in these communities is household crop irrigation with wastewater. It has been argued that wastewater is an alternative source

for agricultural irrigation and a sustainable solution for water scarcity (Asano, 2005). However, in low-income countries, wastewater quality for irrigation is not under control and can be a risk to human health (Vázquez-Salvador et al., 2020). Having a household crop allows communities to diversify their diet; therefore, we consider that restricting irrigation, which comprises a community agreement, represents a potential barrier to access to safe food.

Barriers and bridges around water management

We identified that the lack of water infrastructure and water fetching represents an important barrier on the individual and collective scale. Other studies suggest that water fetching is the highest impact on women and children in poorer rural areas and is likely to be a significant barrier to household water security and sustainable development (Geere & Cortobius, 2017) and a significant risk to health (Geere et al., 2010). Tzisco is the community that performs water fetching in the highest proportion; however, Juznajab and El Triunfo have access to water restricted to certain hours of the day since pump failure is frequent and forces them to seek water from other sources. As described in low- and middle-income countries, households often use more than one source to meet their daily water needs. These can represent an opportunity or bridge to bolster resilience (Elliott et al., 2019).

The collective organization has been one of the key aspects of community-based management (Kearney et al., 2007). The capacity of individuals to organize themselves effectively and together with leadership is often seen as crucial for the initiation of management at the community level (Bodin & Crona, 2008; Olsson et al., 2004). Therefore, a collective organization could be the main bridge for access to water on a collective level since recognition of a collective organization by most community members guarantees compliance. It has been studied that collective values strengthen social ties and promote community participation through norms and agreements established within assemblies or vigilance committees (Barranco, 2020). Establishing a relationship between individuals and their environment means empowering the community to manage its resources as a common good, promoting equity and, in the long term, the sustainability of water use (Agarwal & Narain, 1999).

To develop water management effectively, the role of women as water managers must be recognized and incorporated into the decision-making processes (Geere & Cortobius, 2017). It has been reported that women and girls are responsible for water collection in eight out of 10 households with water off properties (WHO, 2017). In this respect, reducing the time and distance of water fetching is vital because it could improve the amount of water available and foster gender equity in women's decision-making and participation in community-based water management (Panda, 2006).

“Global change, and in particular climate change, pose considerable challenges to water management and governance” (Pahl-Wostl & Kranz, 2010). Uncertainty about rainfall and temperature enhances existing challenges or creates new ones that communities confront concerning water management (Haro et al., 2021; Pahl-Wostl et al., 2010). In these communities, the uncertainty about the rainy season represents a barrier whose implications affect decision-making about the irrigation of domestic crops and the proper use of water sources. To compensate for the variability of the rains, community agreements have been reached on agricultural activities, reforestation plans, and water for irrigation, especially in the dry season, which are considered a collective agreement for adaptation bridge.

Since the study of resource management produces different types of knowledge, it must be integrated into an inclusive framework, which must be flexible and incorporate processes at different scales (Pahl-Wostl & Kranz, 2010). Therefore, this work integrated the analysis of different methods to present a comprehensive perspective of community-based water management. The institutional perspective was not included due to the fieldwork limitations during the pandemic and the government change in Chiapas. To enhance this work, it is necessary to analyze the external factors that shape community-based management. Although the vision of this article is on community water management, it would be enriching to know the current and future position of federal and municipal governmental institutions in the water sector in this region. We consider that understanding the practices around water management and determining barriers and bridges (Pahl-Wostl & Kranz, 2010) contribute to recognizing the importance of

community-based water management in low-income countries and identifying opportunities for change.

Conclusions

We identify barriers and bridges that arise from decision-making processes, through mixed methods, as the first step to addressing community-based water management in marginalized communities in Southern Mexico. We collected evidence in three case studies, where access to water is differentiated by a diversity of practices at an individual and collective level. Our results reveal that these communities have basic-to-unimproved household drinking water services. The lack of water infrastructure and distribution capacity comprise the main barriers to access to water, promoting water fetching, whose implications mainly affect women and children. Through community agreements and norms, the collective organization became the main bridge for access to water on a collective scale. Their recognition by the majority of community members guarantees their compliance for the long term as a present and future strategy for access to water. Decision-making must be considered in an equitable and solidary way, that is, considering within this process the fundamental role that women play in water management since they invest time and effort in access to water for all family members. Finally, it is crucial to recognize the impacts that climate change has on the already established challenges of community-based water management.

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Data availability The datasets generated during and/or analyzed during the current study are available from the corresponding author upon reasonable request.

Declarations

Conflict of interest The authors declare no competing interests.

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