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Integrating equality in evaluation of water access for irrigation in an Andean community

Integrando un enfoque de igualdad en la evaluación de acceso al agua para riego en una comunidad andina

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Resumen

Las estadísticas de desarrollo de Bolivia reflejan considerables diferencias entre grupos sociales y geográficos, por ejemplo, la tasa de pobreza es mucho mayor en comunidades rurales agrícolas, donde las condiciones de vida dependen en gran medida del acceso a recursos hídricos. Las políticas de intervención que ignoran el principio de igualdad, pueden en muchos casos agudizar estas diferencias. En este estudio, evaluamos el acceso al agua para riego en una comunidad Andina, integrando una perspectiva de igualdad basada en la desagregación de datos. Mediante el análisis de datos disponibles, se identificó que la tenencia de derechos de agua y prioridad de distribución son los criterios principales que controlan el acceso al agua en la comunidad. Según estos criterios, la demanda de agua fue desagregada en 28 grupos y todo el sistema fue simulado en el software Water Evaluation and Planning (WEAP), con el que se evaluó la cobertura de demanda de agua. Algunos grupos tuvieron una cobertura de demanda de agua menor al 20%, mientras que otros alcanzaron una cobertura cercana al 100%. Estas diferencias no se pueden observar en el modelo agregado del sistema, para el cual la cobertura de demanda de agua fue superior al 60% todo el tiempo. La evaluación de escenarios de cambio climático indicó que la cobertura de demanda de agua puede reducir en un 15% durante la estación seca. Sin embargo, la implementación de estrategias planificadas podría contrarrestar esta reducción, a través del incremento de provisión e infraestructura de almacenamiento. La implementación de estas estrategias en el modelo indicó que la cobertura de demanda de agua puede aumentar hasta 80% para algunos grupos; sin embargo, otros grupos aún enfrentan escasez. Este estudio hace énfasis en métodos y herramientas de planificación que pueden reforzar los enfoques de igualdad existentes, y aumentar la eficiencia en la reducción de pobreza y desigualdad a través del manejo de agua.

Palabras clave: Igualdad, desagregación, derechos de agua, Andes, WEAP.

Abstract

Development statistics for Bolivia reflect considerable inequalities among people, for instance, poverty rates are much higher in rural agricultural communities, where living conditions depend to a great extent on access to water resources. Many policy interventions ignore the principle of equality, and in some cases even exacerbate differences. In this paper, we examine water access for irrigation in an Andean community, integrating a perspective of equality based on data disaggregation. By analyzing the available data, we identified that tenure of rights and distribution priority are the main criteria that control water access in the community. Based on these criteria, water demand was disaggregated into 28 groups and the system was simulated using the Water Evaluation and Planning (WEAP) software, which allowed us to assess water demand coverage. Some groups receive less than 20% of their water demand, while others receive almost 100%. These inequalities are hidden in an aggregated model, which shows that the entire system never receives less than 60% of water demand. An evaluation of future climate change scenarios showed that water demand coverage could decline a further 15% in the dry season. The implementation of planned strategies, however, could counteract that decline by increasing supply and storage facilities; the model showed that implementing these strategies could raise water demand coverage up to 80% for some groups; however, others still face shortages. This study highlights methods and tools in planning that can strengthen existing equality approaches, and increase the efficiency in reducing poverty and inequality through water management.

Keywords: *Equality, disaggregation, water rights, Andes, WEAP.*

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1. INTRODUCTION

In the past years, poverty and inequality have decreased in Bolivia. Between 2002 and 2017, the percentage of people living in poverty decreased to 35% from 67%, and the Gini coefficient decreased to 0.46 from 0.61. However, recent data show that strong inequalities persist, for instance, the percentage of people living in extreme poverty is 2.95 times higher for indigenous groups, and 5.9 times higher in rural areas (CEPAL 2019). Thus, reduction of inequality remains a very important challenge and there is need to focus on disadvantaged groups.

In the rural areas of Bolivia, 72% of the population practice agriculture (CEPAL 2019). The production conditions of farmers not only control their economic income, but also the level of food security in the region, and the indirect generation of jobs in other sectors such as construction and commerce. To improve these conditions, access to resources such as land, water, supplies, and market must be guaranteed.

Water access relies on existing and new management policies aimed at maximizing water availability, such as infrastructure for storage, distribution, and irrigation optimization (GTZ Sustainet 2008; Ministerio de Medio Ambiente y Agua 2017a). Furthermore, sustainable agriculture incorporates strategies that guarantee higher production, preserve soil productivity, improve climate adaptation, safeguard good nutrition, and offer stable employment (FAO 2002).

However, policies that aim to increase resource availability and sustainability do not necessarily lead to a reduction in poverty and inequality. Policies that do not include an appropriate analysis of inequality risk exacerbating the differences among people and obstructing efforts to reduce poverty. Research can help to capture inequalities between social groups, and provide useful information to develop policies aimed at improving these conditions.

The main purpose of this study is to develop an approach that assesses water access for irrigation in an Andean community, and leads to identify equality challenges of water distribution and potential strategies to confront them. With this aim, we emphasize disaggregation in data collection and analysis, using technical tools that allow simulation in different scenarios.

2. METHODOLOGY

In this section, we first present political and socioeconomic circumstances that affect communities in the region, and the physical characteristics of the study area. Then, we describe the analysis of available data and the disaggregation of demand in WEAP for present and future scenarios.

2.1 Characteristics of agricultural communities in the Bolivian Andes

In rural areas, current access to natural resources is defined by physical, historical and socioeconomic factors that have also shaped the differences among communities and individuals.

Historically, in the Bolivian Andes, those who had control over territory were also in charge of managing water resources. The pre-colonial period, mainly represented by the Incan empire, is characterized by the conditional distribution of land to indigenous groups. After the conquest, Spaniards ruled based on systematic dispossession and exploitation. For indigenous people, this period marked the beginning of a permanent struggle to obtain recognition of their rights and property. In the post-colonial stage, republican governments undertook the difficult process of resource redistribution. However, until recent decades, social struggles continued caused by certain policies that created disadvantages by omitting indigenous groups (Crespo and Fernández 2001). For instance, the Agrarian Reform of 1953 distributed territory to peasants, but ignored indigenous groups, and granted land titles only to men (this was partially amended by the INRA Law of 1996 and the Community Conversion Law of 2006) (Razavi 2012; Beccar and Hoogendam 2010). In 2000, the government attempted to implement privatization policies that conceded control of water resources to private companies, completely ignoring the management and control mechanisms of local communities (Crespo and Fernández 2001). This situation led to widespread protests rejecting privatization and demanding recognition of their rights. As a result, in 2006, the current Irrigation Law was implemented, recognizing water management according to "uses and customs" and the rights of communities that register their water sources. However, this Law ignores those who do not water source, overlooks principles of equality and control of abuses, and requires a registration process that has generated competition and conflicts between communities (Razavi 2012; Seemann 2016). At present, the implementation of policies in the water sector is framed by this legal instrument, and also follows the guidelines of public institutions, funders, and executors that integrate their own equality focus and mechanisms.

Inequalities in rural areas can be exacerbated by other processes, such as agricultural land conversion that mainly occurs due to urbanization and increase in land value (Löhr 2010). The highest conversion rates are found in underdeveloped countries, as their cities experience faster growth (Azadi et al. 2010); and most global conversion affects fertile lands (Bren d'Amour et al. 2017). Although conversion is perceived as an inevitable process to achieve development, it has many negative impacts, such as a reduction in agricultural production, more competition for water sources, the need for residents to acquire new skills, and the loss of agriculture-related knowledge and cultural practices. These consequences are worse for disadvantaged groups, who have fewer resources to endure this process.

The gender distribution of water rights in Andean agricultural communities is influenced by different factors. Beccar and Hoogendam (2010) explain that most men inherit land property (usually linked to water rights) because of the persistence of colonial traditions and the physical nature of agricultural work; men usually perform heavier tasks, while women perform those that require patience and dexterity (Morlon 1996; Gisbert et al. 1994). When agriculture is not enough for subsistence, men migrate to mines or cities; as a result, women assume all the tasks that men had and the representation of water rights, which includes participating in decision-making. In some cases, work overload for women has a toll on soil conservation, causing lower productivity (Ashwill et al. 2011; Gisbert et al. 1994). With industrialization, the purpose of agriculture changed from survival to capital generation (Arratia and Sánchez 1998). For women, domestic tasks became more devalued as they do not generate capital (Zwarteveen 2010). In addition, the assumption that men are the only "producers" and decision-makers is reflected in biased allocation of resources such as water (Zwarteveen 1997; van Koppen 1998; Twyman et al. 2015).

2.2 Study Area

The community of Marquina is located within the boundaries of the Quillacollo Province in the Department of Cochabamba. It is situated in the valleys of the Andean eastern cordillera (see Figure 1). Climate is temperate with a dry winter, and rainy austral summer with an average annual rainfall of 600 millimeters. The average mean temperature is 18°C.

Marquina's proximity to the Chocaya River, climate and soil conditions have favored agricultural activity. The sources of water for irrigation are river streamflow and reservoir releases from El Toro and Marquina; stored water is shared with the communities Bella Vista (upstream) and Paucarpata (downstream).

Water is distributed through a system of open channels presented in Figure 1. The network has a main branch (1), one partially isolated (2), and the rest labeled in clockwise order. Drinking water systems are independent and were not included in this analysis.

The cultivated area is approximately 72 hectares and the most profitable products are flowers, fruits, potatoes, vegetables, maize, alfalfa, legumes, and herbs. Climate and weather conditions that affect production are water scarcity, hail and frost. Production costs depend largely on whether a farm needs to hire labor or can rely solely on family members, and sale prices are determined by variable market conditions.

The closest urban area is Quillacollo city, which is 14.5 kilometers south of Marquina. In recent years, uncontrolled urban sprawl has led to land fragmentation and disorganized house construction. This process of land conversion risks the preservation of agriculture; moreover, an increasing population and water demand pose a threat to irrigation water sources. In response, the Organization of Irrigators from Marquina has demanded that authorities implement measures that guarantee water availability and optimize irrigation practices.

2.3 Water rights for irrigation

Water rights systems in the region are complex, as they combine principles of Andean cultures and colonial practices whose norms interact in the same territory, also known as legal pluralism (von Benda-Beckmann et al. 1997). In Marquina, there are three types of water rights: the system of "mit'a" or turns; releases of reservoirs or "largadas"; and "aguas comunes" or free distribution. In addition to water access, these rights include restrictions, sanctions, and obligations to participate in decision-making processes about the system (Beccar et al. 2002).

The mit'a was implemented in the pre-colonial period when river streamflow was distributed to subregions following principles of Andean rationality, complementarity, reciprocity, equality, and rotation; these principles are also reflected in the collective management and maintenance of water infrastructure (Morlon 1996; Gerbrandy and Hoogendam 1998; Crespo and Fernández 2001). The reservoirs were built during and after the colonial period, and those who participated in the construction became beneficiaries, also known as hydraulic property creation (Coward 1990). Over time, these rights were transferred through other mechanisms such as inheritance, sale and rent (Boelens and Doornbos 2001). In figure 1, plots of beneficiaries for each network branch are coded by color; those with more water rights are indicated with higher color saturation. For all systems, distribution priority diminishes downstream the diversion point.

The amount of monthly rainfall and river streamflow indicate the enforcement of each right: common waters during the rainy season (December to March), mit'a from April to October, and reservoir gates open in the period of minimum river flow (August to November). The characteristics are presented in table 1.

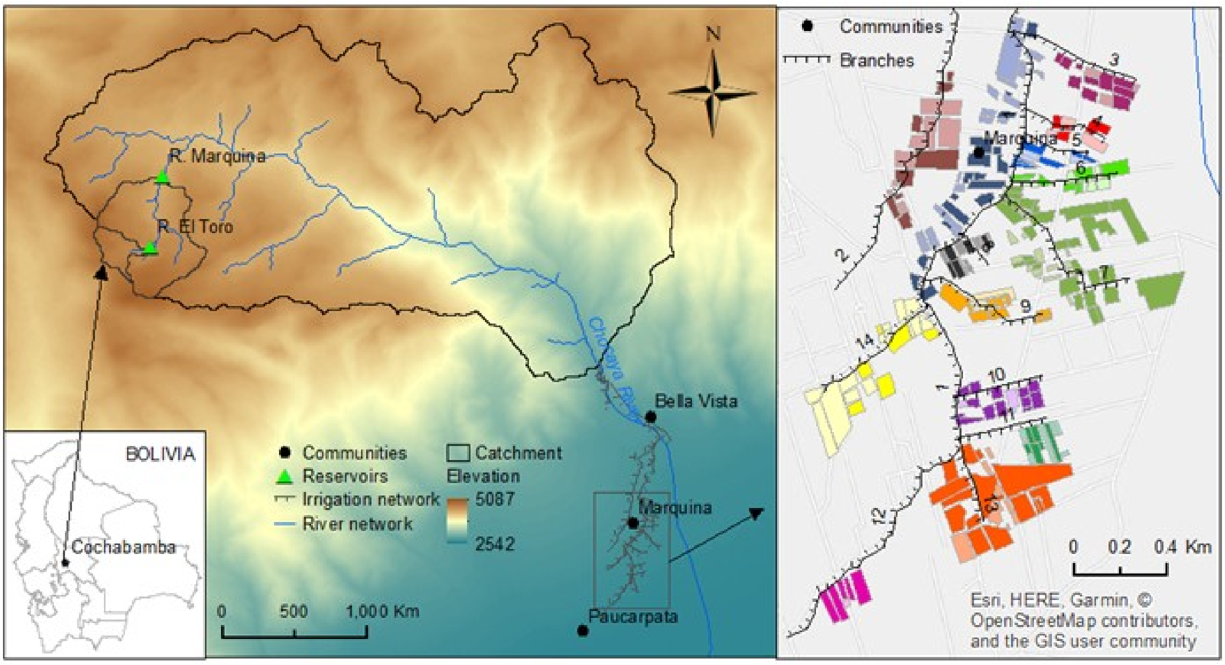


Figure 1. Location of the study area (left) and the irrigation network in Marquina (right). Cultivated plots are color coded by branch, with higher saturation indicating more water rights.

Table 1. Characteristics of water rights

Right	Source	Months	Turn	Acquisition mechanism
Aguas comunes	Surface flow of Chocaya river	Dec-Mar	No limit	By default
Mit’a	Subsurface flow of Chocaya river	Apr-Oct	5 to 60 minutes every 20 days	Linked with land, hereditary, sale
El Toro	Reservoir	Aug-Oct	30 to 60 minutes per release	Hydraulic property creation, hereditary, sale
Marquina	Reservoir	Nov		

2.4 Analysis of available data

The Organization of Irrigators provided lists that contain information on the branches, cultivated areas, water rights, and representatives of 255 families; these persons are not necessarily land or water right owners, but they have the authority to represent family interests in regards to water access for agriculture. The variability of water rights was analyzed based on type of right, area, gender and branch; data about social class was not available for Marquina. This analysis aims to explore which factors may influence water access, excluding other circumstances such as infrastructure status, irregular distribution, or illegal diversions; for which information is not available and is difficult to identify.

2.5 Configuration of WEAP model for the baseline scenario (1980-2014)

The Water Evaluation and Planning (WEAP) system is an integrated water resources management model that can simulate offer and demand processes, considering user-defined priorities and preferences. In the model, we can configure hydrology, infrastructure operation, environmental processes, and different types of demand on different levels of hierarchy and time scales (Yates et al. 2005). In addition, we can simulate present and future scenarios of climate, land use, strategy implementation, population growth or any other factor that affects water resources.

WEAP has been implemented in Bolivia to simulate water resources under climate change uncertainty in the cities of El Alto and La Paz (Escobar et al. 2013), and to develop the National Water Balance for 1980-2016 (Ministerio de Medio Ambiente y Agua 2017b). At present, it is used to develop the Plan of Rocha basin in Cochabamba and to integrate water access and sanitation planning with river basin management in Tupiza.

Because of WEAP’s flexibility in data configuration, which makes it capable to fit any context, we were able to represent the complex distribution of water rights and disaggregate demand data.

The community of Marquina was represented in WEAP in two forms: 1) as a single demand node, as is usual in watershed level modeling, and 2) as a disaggregated model with numerous nodes. Data should be disaggregated based on factors that have the most impact on water access for irrigation – for example, tenure of water rights, location within the distribution network, affordability of water charges, and capacity to build irrigation infrastructure. These factors are case-specific and may also depend on social class and gender, as they are closely related to historic, cultural and socioeconomic characteristics. In this study, we used the available data to identify the main factors that affect water access in Marquina, recognizing the limitations due to the lack of other information.

Below we present details of input data for the processes of rainfall-runoff, reservoir operation, water distribution, and demand for the baseline period, defined as from 1980 to 2014.

Rainfall-runoff simulation requires meteorological and hydrologic data. In the absence of stations within the study area, we used baseline data from the Bolivian National Water Balance (Ministerio de Medio Ambiente y Agua 2017b), including the regional gridded daily series of rainfall and temperature interpolated with the GMET tool (Newman et al. 2015) and adjusted for altitude effects. Humidity, wind speed, and cloudiness data were interpolated from curves obtained with regional observed data for different elevation ranges. Land coverage information was obtained from the European Space Agency and soil type data from the Food and Agriculture Organization. In WEAP, the soil moisture method described in Yates et al. (2005) was used to simulate the rainfall-runoff process.

Since the river lacks hydrometric stations, model parameters could not be adjusted based on flow data. As an alternative, we used available data on reservoir storage levels and releases to validate model parameters.

Reservoir operation requires data of maximum storage capacity and dam height, both obtained from the National Dam Inventory (Viceministerio de Recursos Hídricos y Riego 2010). To simulate dam releases we used the element Flow Requirement, and set the minimum flow needed to empty the reservoir during the months of enforcement. Table 2 indicates the expressions for minimum flow requirement for each month (mon) for Marquina reservoir and mit’a, where STOmon and SMAmon are the active volume stored in El Toro and Marquina, and smon is the number of seconds. The Marquina reservoir is located on the same reach downstream as El Toro; thus, from August through October, it stores and releases volume from El Toro. For mit’a, the minimum flow requirement is a fraction of Qmon, which is the streamflow at the diversion point where community representatives distribute water based on these approximated fractions. The increase during the dry season reflects higher demand and less water availability.

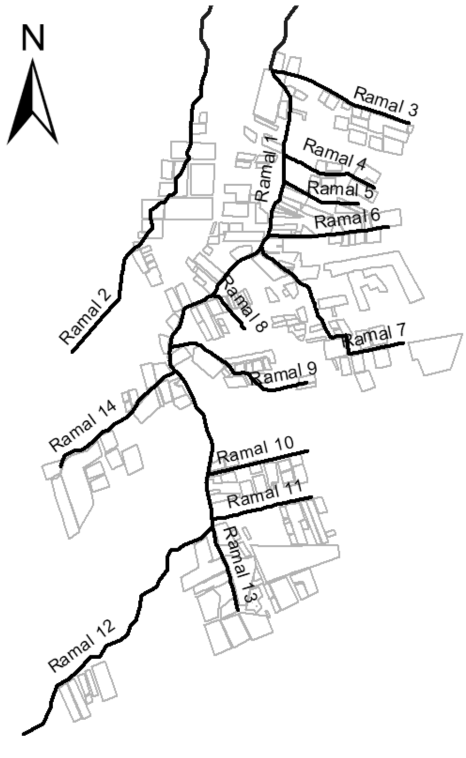
Table 2. Minimum Flow requirements at the main diversion (for all communities)

Month	Marquina [m^3/s]	Mit'a [m^3/s]	Month	Marquina [m^3/s]	Mit'a [m^3/s]
Jan	0	0	Jul	0	$0.4*Q_{Jun}$
Feb	0	0	Aug	$STO_{Jul}/(3*s_{Jul})$	$0.5*Q_{Jul}$
Mar	0	0	Sep	$STO_{Aug}/(2*s_{Aug})$	$0.5*Q_{Aug}$
Apr	0	0.3	Oct	$STO_{Sep}/(1*s_{Sep})$	$0.5*Q_{Sep}$
May	0	$0.3*Q_{Apr}$	Nov	$SMA_{Oct}/(1*s_{Oct})$	0
Jun	0	$0.4*Q_{May}$	Dec	0	0

Table 3. Distribution factors per community and water right

Community	Mit'a	El Toro	Marquina
Bella Vista	0.5	0	0.25
Marquina	0.4	0.75	0.5
Paucarpata	0.1	0.25	0.25

Table 4. Distribution factors per water right and network branch

Network	Branch	Mit'a	El Toro	Marquina
	1	0.028	0.132	0.174
	2	0.000	0.075	0.075
	3	0.028	0.074	0.059
	4	0.028	0.037	0.034
	5	0.056	0.051	0.047
	6	0.097	0.051	0.055
	7	0.056	0.206	0.182
	8	0.042	0.037	0.064
	9	0.139	0.066	0.051
	10	0.083	0.096	0.068
	11	0.028	0.044	0.055
	12	0.139	0.037	0.025
	13	0.139	0.118	0.102
	14	0.139	0.051	0.085

To represent water distribution, we used Diversions and Flow Requirements, for which equal expressions of Maximum Flow and Minimum Flow Requirement were defined. For each month, the volume of the source (river or reservoir) of the previous time step was multiplied by the branch's fraction of water rights with respect to the total. Table 3 presents the fixed distributing factors for each community and right, that multiply the expressions presented in table 2. Also, table 4 presents fixed distribution values per branch that multiply the last result.

Water delivery from diversions to demand nodes is represented with Transmission Links. The configuration of demand nodes for irrigation requires the Annual Activity Level (cultivated area) and the Annual Water Use Rate (total annual irrigation demand). This was calculated with the methods described in the FAO Manual (Allen et al. 1998) for six typical crop rotations: corn-potato, onion-legumes, flowers, fruits, herbs, and alfalfa. Finally, Loss Rate was estimated to be 0.7, considering flood irrigation and an estimation of other losses.

Figure 2 presents the configuration of Marquina as a single node in WEAP, and the diversions for the other communities. We used the codes Ac (common waters), Mi (mit'a), LM (Marquina reservoir) and To (El Toro reservoir) to represent each water right diversion and flow requirement. The schematic of the disaggregated model is presented in Section 3.1.

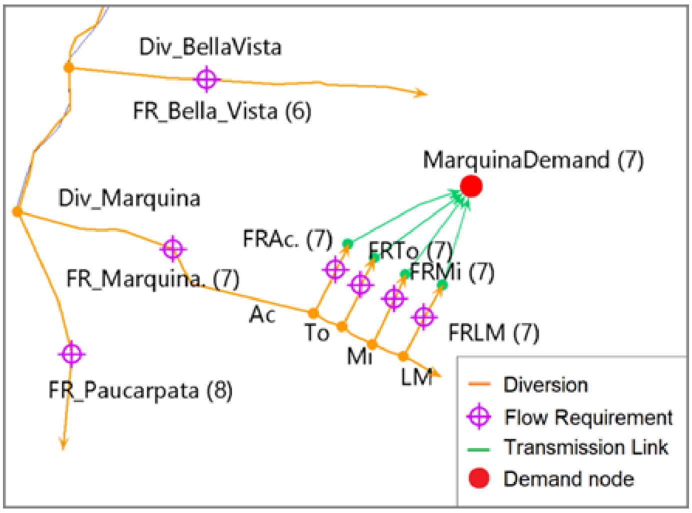


Figure 2. Schematic view of aggregated model of Marquina in WEAP

2.6 Definition of future scenarios

The period for future analysis is 2015-2049. Four scenarios were defined for climate change, and four were defined for implementation of planned measures.

We used global climate models that were previously evaluated in Ministerio de Medio Ambiente y Agua (2017) and showed more similarities with historic climate characteristics at national (CCSM4, MPI-ESM-LR) and local scale (CESM1CAM5, IPSL-CM5A). We selected the most pessimistic trends of greenhouse gas emissions for all global climate models, assuming that they will continuously rise in the future (Representative Concentration Path 8.5).

The downscaling process was performed using the statistical nonparametric method K-NN (Gangopadhyay and Clark 2005), which consists of the construction of synthetic series as sequences of historical observations that preserve statistical characteristics. The main advantages of this method are that it captures the climatic attributes of the observations and preserves their spatial correlation.

The scenarios of strategy implementation included planned measures to optimize water management and increase availability, while ensuring the preservation of agricultural practices. The four scenarios were:

- Measure 1: Raise the height of the Marquina reservoir dam to increase storage capacity (1.25 times larger), with no change in distribution factors and the month of enforcement.

• Measure 2: Release additional 120 liters/second of the Misicuni Project (dam), distributed during May-July.

• Measure 3: Implement a sprinkler irrigation system, reducing the total loss rate from 0.7 to 0.3

• Measure 4: Build storage tanks, one in Branch 1 (the main branch) and the other in Branch 2, with releases set from April to July.

3. RESULTS AND DISCUSSION

In this section, we first present the results of the disaggregated analysis, and then the results of simulation in the present and future scenarios.

3.1. Analysis of available data

The list from the Organization of Irrigators contained information on the branches, cultivated areas, water rights, and representatives of 255 families. Water rights were analyzed based on the type of right, cultivated area per branch and gender. The aim of this analysis was to identify the factors that have more influence in water access, however, it was not possible to assess the effect of other circumstances such as infrastructure status, irregular distribution, or illegal diversions because this type of information is difficult to identify and it was not available.

Water rights are expressed as turns (seconds) accumulated per month from 0 to 10 hours. These turns can be distributed one to four times in a month, depending on the right and water availability.

The distribution based on type of water right, shows that the largest variation corresponds to mit’a, mainly due to irregular and heterogeneous land fragmentation that affected the rights linked to territory. The allocation process also did not benefit Branch 2 because of the branch’s location and soil characteristics. The variability for El Toro rights reflects the investment of labor during the construction (simple or double). In the case of water rights for the Marquina reservoir, every farmer has the same turn.

Figure 3 indicates the total branch area (sorted in ascending order) and the corresponding right/area ratio for each water right. This ratio helps us to identify the branches where water rights may be concentrated or lacking. For instance, the branches with the greatest ratio are 10, 12 and 8, and the branches with the lowest ratio are 14, 13 and 1 for El Toro, mit’a, and Marquina respectively. Although a comparison of turns does not reflect water volume or priority, it provides a preliminary assessment that disadvantaged groups could be located in branches 1, 2, 13 and 14. In addition, we calculated the distribution of representatives (i.e. farmers) per area, the results show that 10% of representatives manage plots larger than one hectare, which corresponds to 35% of the total agricultural area.

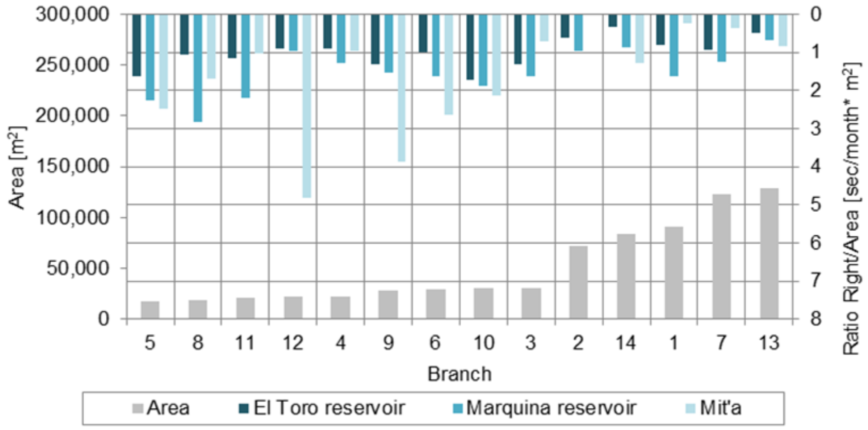


Figure 3 Cultivated Area per branch (sorted in ascending order) (m^2) and Right/area ratio (seconds/ month*m^2)

The gender distribution of water rights indicates that 48% correspond to male and 52% to female representatives. In addition, we calculated the distribution of representatives (48% man and 52% women) and control of plot area (50% for male and female representatives). These percentages do not reflect ownership, which remains mostly male as reflected in other communities in the region; for instance, near the small city of Punata, the average percentage of female water rights’s owners is 30%

(Saldías et al. 2011). Data collected from a smaller sample (150 users) shows no preferences of cultivated crop based on gender. Similarly, gender distribution of representatives per branch is even, which suggest that there are no considerable differences in priority. These results ignore other circumstances that may affect water access because of limited data.

3.2 Demand Disaggregation

The available information indicates that the main factors that influence water access are the tenure of a certain water right (mit'a, El Toro or Marquina), and priority which depends on the plot location within the network. Other specific circumstances such as state of plot-level irrigation infrastructure, irregular distribution or illegal diversions were not accounted for because of the lack of data.

Therefore, the disaggregation criteria for demand were based on water rights combination per branch. Figure 4 presents the schematic of the dissagregated model in WEAP, the network has 14 branches, and for each branch we found two combinations or water rights, that form the groups AcLM2, AcLMTo2, and for the rest of the branches AcMiLM#Branch and AcMiLMTo#Branch. In total, there are 28 groups or disaggregated demand nodes.

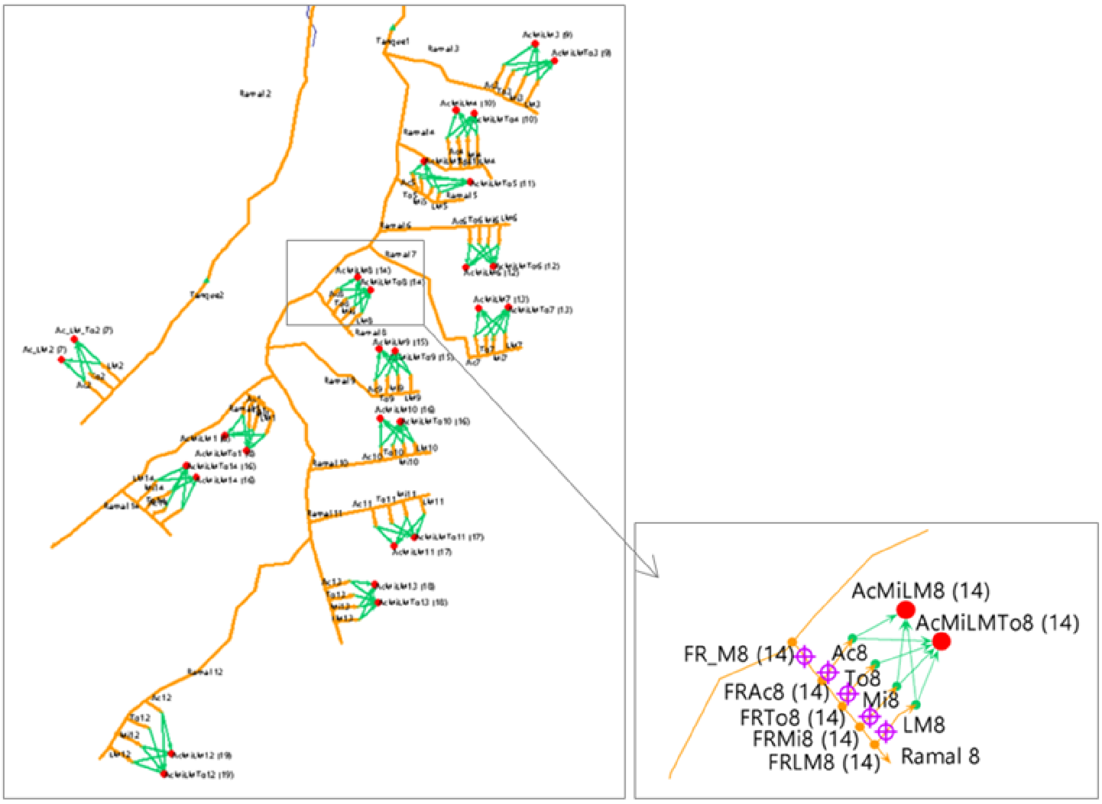


Figure 4. Schematic of disaggregated model of Marquina in WEAP

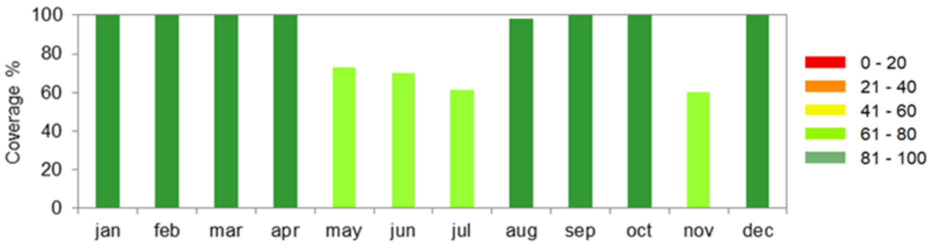


Figure 5. Average monthly coverage for aggregated model

3.3. Simulation results for the baseline period 1980-2014

The results of the aggregated model for the baseline period are presented in Figure 5, we can see that the average monthly coverage has a minimum of 60% in July and November. This result could be the only available information indicating the degree to which irrigators need funding for water management projects. In general, funding is approved for communities that present critical conditions of coverage overall, thus, Marquina is likely not a priority. However, decision-making based on this information fails to address possible inequalities among farmers and prevents that small disadvantaged groups in critical conditions improve their situation. The results of the disaggregated model are presented in Figure 6 and Figure 7. The average monthly coverage indicates that branches 1, 2, 3, 7, 12, 13 have less than 20% of coverage in the dry season. We can also distinguish the benefits for the plots that have El Toro rights in branches 2 and 12, with greater coverage during August-October. In branch 12, despite the greater right/area ratio for mit'a, there is a shortage due to low priority. The branches that have high coverage every month are 5, 6, 8, 9, 10 and 14; all of them have high right/area ratios for each right, except branch 14 that is benefited because of priority. The results of the model allow us to go beyond the theoretical allocation of water rights and reveal which groups experience critical shortages. Unlike the results of the aggregated model that indicate regular to good coverage (61-80%) throughout the system in the dry season, the disaggregated model reveals the 4 branches with a critical situation (<20%), and that actions are required to improve the conditions of these specific groups.

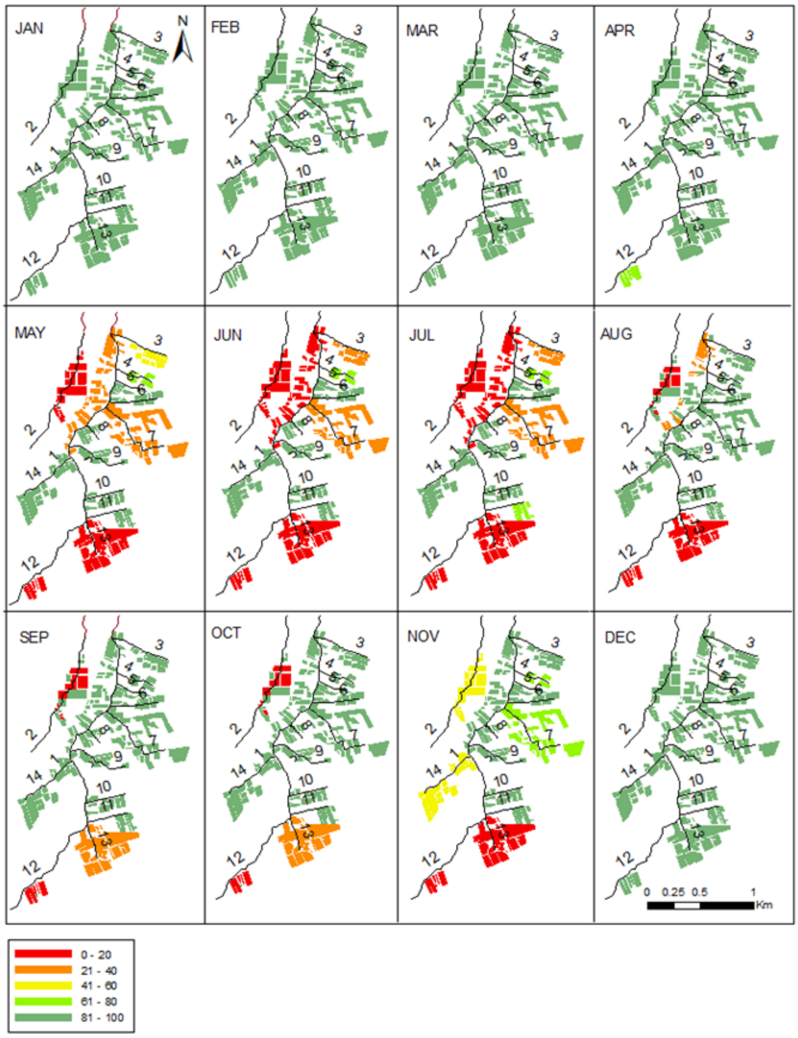


Figure 6. Average monthly coverage for disaggregated model, branch number indicated

3.4. Climate change scenarios

The results of climate change analysis are presented in Table 5. Mean annual temperature increased for all scenarios by 1.2˚C to 1.7˚C, with the highest seasonal increase occurring in winter (+2˚C) and the lowest occurring in summer (+0.5˚C). The change in average annual rainfall is +4% to +11% for all models except MPI-ESM-LR, which indicates -3%. During the first months of the wet period (December-February), monthly rainfall increases for all scenarios (up to 30%) and from February-May, it decreases (up to -15%). Changes in the dry season are negligible. These results are similar to those found at the regional scale (Rocha river basin), that show changes in average temperature of +1.3 to +1.7˚C, and percentage changes in annual rainfall of +1 to +5% (Stockholm Environment Institute, 2017).

Annual irrigation demand is higher (+7% to +15%) under all climate scenarios. On the other hand, changes for annual volume of surface runoff varies widely from -19% (for MPI-ESM-LR) to +21%. Monthly values increase during December-January for all models (except MPI-ESM-LR), decrease from February to March, and present small reductions in the dry season.

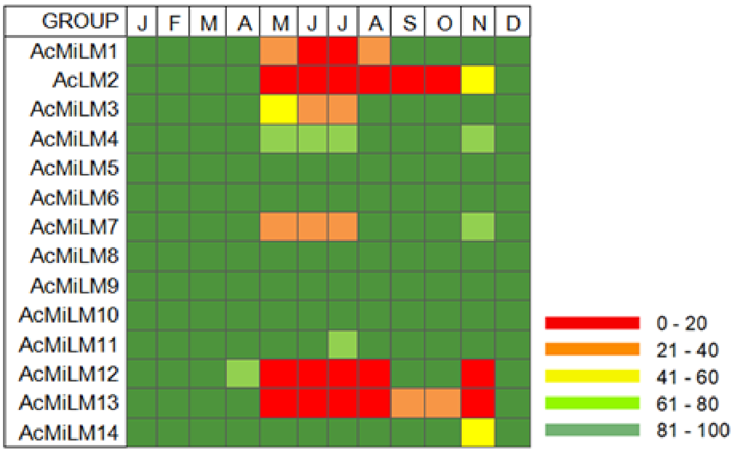


Figure 7. Average monthly coverage per branch for the groups with fewer water rights

Table 5. Change of variables under climate change scenarios

Change	**CCSM4**	**CESM1CAM5**	**IPSL-CM5A**	**MPI-ESM-LR**
Annual rainfall (%)	4.0	11.8	6.7	-3.5
Mean annual temperature (˚C)	1.2	1.3	1.7	1.6
Annual demand (%)	7.3	9.1	15.1	14.1
Mean annual surface runoff (%)	0.0	20.9	7.5	-18.7

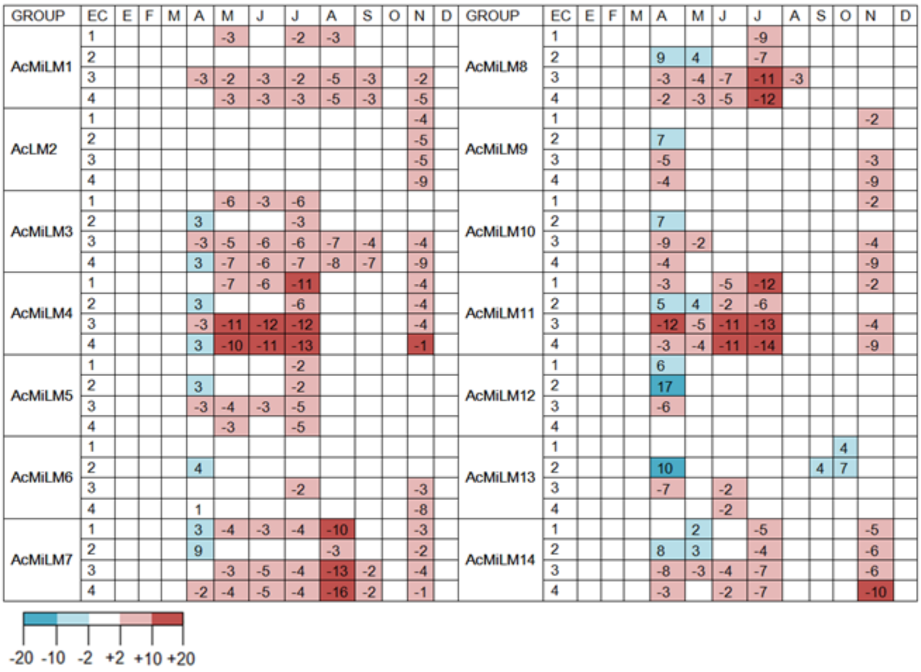
Figure 8 shows the absolute change in average monthly coverage for the groups with fewer water rights. In general, there is a decrease during the dry season that is more severe (-15%) for branches 4, 8, 11, and 7. Only in April, there are increments up to +17% for branches 7, 8, 12 and 13. There are almost no changes for branches 9 and 12, which remain with no coverage in the dry season. The smallest changes correspond to CESM1CAM5 model and the largest to MPI-ESM-LR.

3.5. Implementation of strategies

The measures with the greatest impact are Measure 2 (release additional water from Misiscuni Project) that increases the supply, and Measure 4 (build storage tanks in Branch 1 and 2) that improves management with small reservoirs (See Figure 9 and Figure 10).

The implementation of Measure 3 (sprinkler irrigation) improves coverage as well, but not for Branches 1, 2, 12 and 13, in part because low priority and lack of water rights are not solved with this measure. The measure with the least impact is 1 (increase volume of the Marquina reservoir) that results in a small change, note that the volume is shared with two other communities and is only released in November when coverage is not critical.

Despite the improvements with Measures 2 and 4, there is still scarcity in August and November for Branches 2, 12 and 13. Therefore, it is necessary to modify the strategies, integrating a perspective of equality to address these differences, or to propose new ones.



GROUP	EC	E	F	M	A	M	J	J	A	S	O	N	D
AcMiLM1	1					-3		-2	-3				
	2												
	3				-3	-2	-3	-2	-5	-3		-2	
	4					-3	-3	-3	-5	-3		-5	
AcLM2	1											-4	
	2											-5	
	3											-5	
	4											-9	
AcMiLM3	1					-6	-3	-6					
	2				3			-3					
	3				-3	-5	-6	-6	-7	-4		-4	
	4				3	-7	-6	-7	-8	-7		-9	
AcMiLM4	1					-7	-6	-11				-4	
	2				3			-6				-4	
	3				-3	-11	-12	-12				-4	
	4				3	-10	-11	-13				-1	
AcMiLM5	1							-2					
	2				3			-2					
	3				-3	-4	-3	-5					
	4					-3		-5					
AcMiLM6	1												
	2				4								
	3							-2				-3	
	4				1							-8	
AcMiLM7	1				3	-4	-3	-4	-10			-3	
	2				9				-3			-2	
	3					-3	-5	-4	-13	-2		-4	
	4				-2	-4	-5	-4	-16	-2		-1	
AcMiLM8	1							-9					
	2				9	4		-7					
	3				-3	-4	-7	-11	-3				
	4				-2	-3	-5	-12					
AcMiLM9	1											-2	
	2				7								
	3				-5							-3	
	4				-4							-9	
AcMiLM10	1											-2	
	2				7								
	3				-9	-2						-4	
	4				-4							-9	
AcMiLM11	1				-3		-5	-12				-2	
	2				5	4	-2	-6					
	3				-12	-5	-11	-13				-4	
	4				-3	-4	-11	-14				-9	
AcMiLM12	1				6								
	2				17								
	3				-6								
	4												
AcMiLM13	1										4		
	2				10					4	7		
	3				-7		-2						
	4						-2						
AcMiLM14	1					2		-5				-5	
	2				8	3		-4				-6	
	3				-8	-3	-4	-7				-6	
	4				-3		-2	-7				-10	

Figure 8. Absolute average monthly changes in coverage for the groups with fewer rights per branch, and for climate change scenarios: 1 CCSM4, 2 CESM1-CAM5, 3 IPSL-CM5A, 4 MPI-ESM-LR

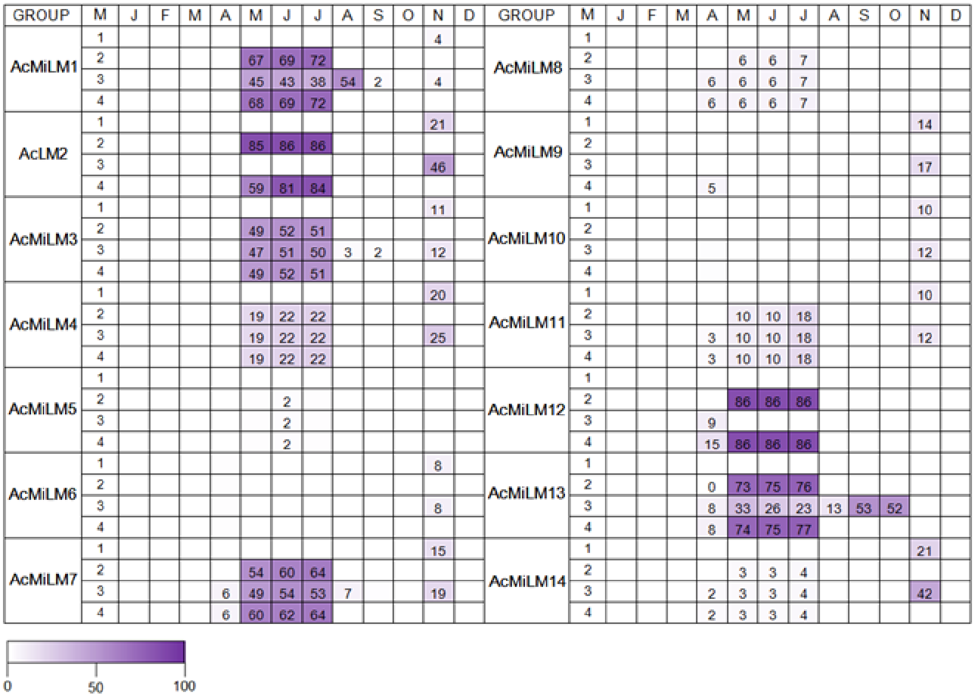
The combined results of climate change and implementation of measures are presented in Figure 11. We can see that the differences in annual coverage for projections of climate change are negligible. On the other hand, changes for measures 2 and 4 increase annual coverage by 20% for some branches.

The main sources of uncertainty in this study were related to limitation of data. Some aspects that may affect water access such as status of infrastructure, irregular distribution, or illegal diversions were not considered, as these situations are difficult to identify, register and collect.

In the simulation process, due to lack of meteorological stations, we used regional data and adjusted some of the variables considering geographic characteristics. We recommend installing meteorological stations in strategic places that cover representative geography and communities. In regards to hydrometric stations, performing flow measurements regularly can provide useful information and support farmers in control activities.

There is also uncertainty related to reservoir data, as infrastructure damages such as fractures may reduce maximum storage volume. It is necessary to carry field campaigns to update geometric information and to perform routine checks to improve operation conditions.

In regards to water distribution, gates are operated manually and flow is not distributed as precisely as in the model. We recommend implementing measurement devices to better quantify system losses due to infiltration or illegal extractions.



GROUP	M	J	F	M	A	M	J	J	A	S	O	N	D
AcMiLM1	1											4	
	2					67	69	72					
	3					45	43	38	54	2		4	
	4					68	69	72					
AcLM2	1											21	
	2					85	86	86					
	3											46	
	4					59	81	84					
AcMiLM3	1											11	
	2					49	52	51					
	3					47	51	50	3	2		12	
	4					49	52	51					
AcMiLM4	1											20	
	2					19	22	22					
	3					19	22	22				25	
	4					19	22	22					
AcMiLM5	1												
	2						2						
	3						2						
	4						2						
AcMiLM6	1											8	
	2												
	3											8	
	4												
AcMiLM7	1											15	
	2					54	60	64					
	3				6	49	54	53	7			19	
	4				6	60	62	64					

GROUP	M	J	F	M	A	M	J	J	A	S	O	N	D
AcMiLM8	1												
	2					6	6	7					
	3				6	6	6	7					
	4				6	6	6	7					
AcMiLM9	1											14	
	2												
	3											17	
	4				5								
AcMiLM10	1											10	
	2												
	3											12	
	4												
AcMiLM11	1											10	
	2					10	10	18					
	3				3	10	10	18				12	
	4				3	10	10	18					
AcMiLM12	1												
	2					86	86	86					
	3				9								
	4				15	86	86	86					
AcMiLM13	1												
	2				0	73	75	76					
	3				8	33	26	23	13	53	52		
	4				8	74	75	77					
AcMiLM14	1											21	
	2					3	3	4					
	3				2	3	3	4				42	
	4				2	3	3	4					

Figure 9. Absolute average monthly changes in coverage for the groups with fewer rights per branch, and for the implementation of measures: 1 Increase volume of Marquina, 2 Misicuni supply, 3 Sprinkler irrigation, 4 Storage tanks.

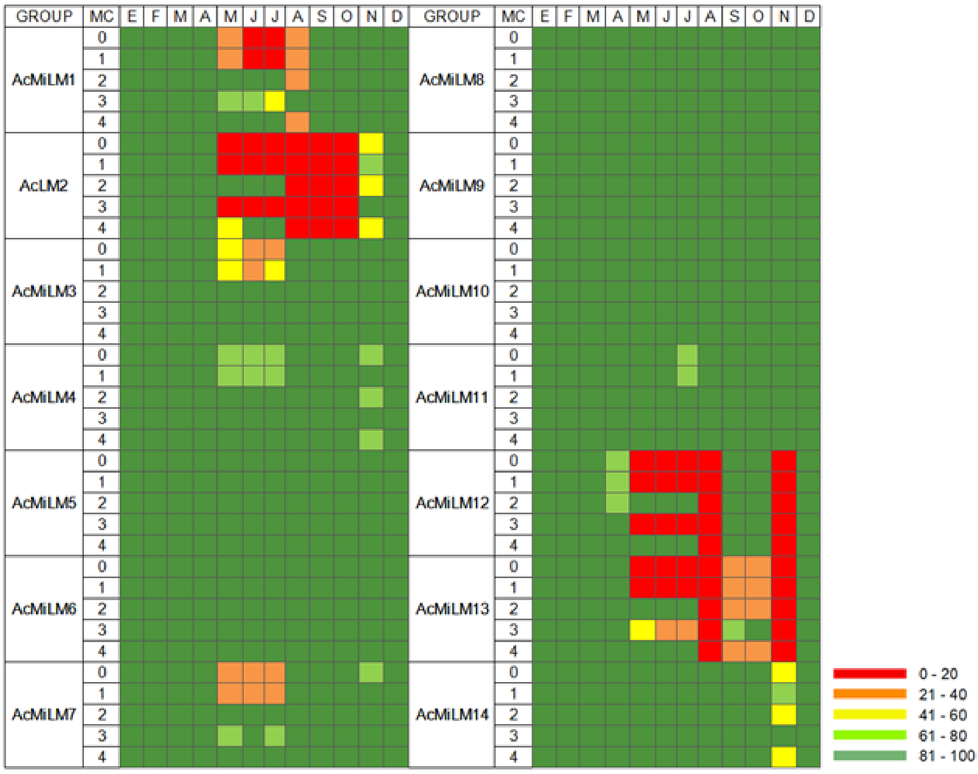


Figure 10. Average monthly coverage for the groups with fewer rights per branch, and for the implementation of measures: 0 No measure, 1 Increase volume of Marquina, 2 Misicuni supply, 3 Sprinkler irrigation, 4 Storage tanks.

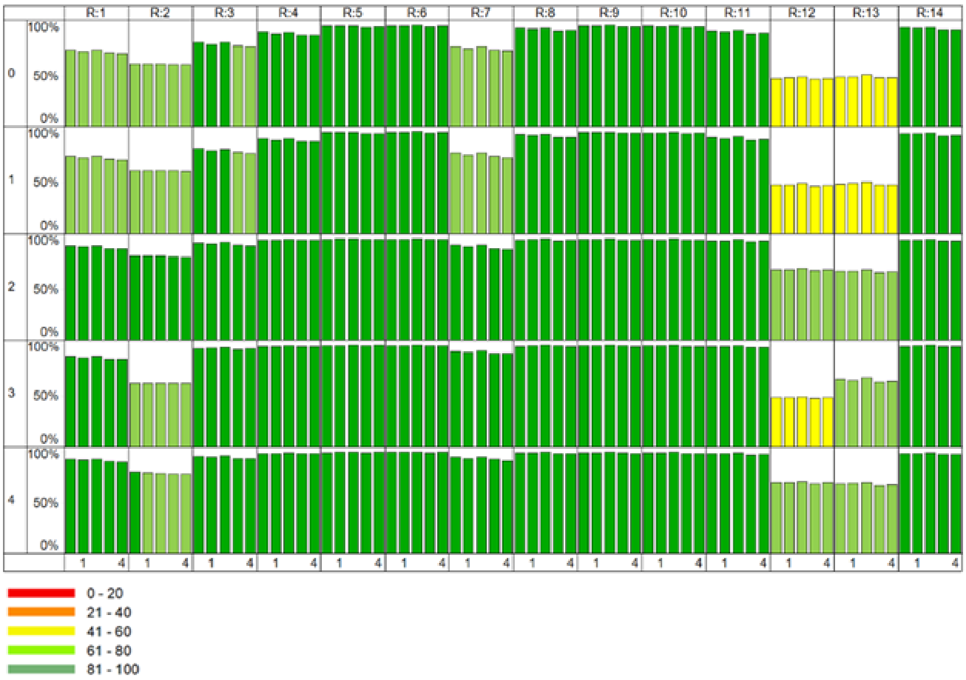


Figure 11. Average annual coverage results per branch, measure (rows) and climate change scenario. Measures: 0 No measure, 1 Increase volume of Marquina, 2 Misicuni supply, 3 sprinkler irrigation, 4 storage tanks. Scenarios: 0 No change, 1 CCSM4, 2 CESM1-CAM5, 3 IPSL-CM5A, 4 MPI-ESM-LR

4. CONCLUSIONS

In this study, we integrated a focus of equality to evaluate water access for irrigation in an Andean community. First, we analyzed available data to identify which factors may have more influence on water access, and then we used them to disaggregate demand in the WEAP model.

The available data suggested that water access for irrigators in Marquina depends mainly on tenure of water rights of a certain system and distribution priority. The aspects that determine water rights are case-specific and depend on the mechanisms of water rights allocation and transfer. These are also influenced by population growth, land fragmentation and migration.

The WEAP software allowed us to represent the demand in an aggregated and disaggregated manner, demonstrating the benefits of addressing inequalities by disaggregating the relevant details of water rights and distribution in this particular community. The model provides flexibility to create new variables and expressions relevant to a specific community, and this example provides an application that could be useful for other regions.

The results of the disaggregated simulation showed that a small number of groups face shortages with a coverage of lower than 20% in the dry season. These groups have fewer water rights or lower priority as they are located downstream. This shortage is slightly worsened in future climate change scenarios as coverage further reduces by 15% in the dry season. Results show higher coverage with improvements in water availability with the Misicuni project and additional water storage. However, without the integration of an equality-based approach for water distribution, some groups in the community will still face shortages despite the benefits of this water transfer.

Currently, studies that integrate equality considerations in planning-based research and in the evaluation of adaptation strategies are scarce. Most studies are done at the watershed scale to obtain integrated water management plans, without delving into the details of specific communities. In these studies, it is likely that the internal inequalities of communities are not highlighted or addressed. In general, the data collection activities require a high level of detail to obtain complete disaggregated datasets, which increases complexity and time requirement to simulate present and future scenarios, and to evaluate the impact strategies on the solution of water allocation inequalities.

In addition, ex-post evaluation of water management strategies are limited, thus, the level at which objectives and sustainability were fulfilled are mostly unknown. A disaggregated, systematic and objective assessment of a concluded strategy can help us find how benefits were distributed within the community and what contributed to reduce or increase inequality.

Implementing the methodology of this study in other communities can help promote equality-based approaches and improve our understanding of the aspects that affect water access in different contexts, and in particular the factors that affect disadvantaged groups. Furthermore, analyzing access to other resources –such as farm input supplies and capital markets– can provide a wider socio-economic perspective. Doing so, will undoubtedly require more investment but will surely contribute to the challenging task of reducing poverty and inequality.

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