Agricultural Water Management 297 (2024) 108783

Contents lists available at ScienceDirect

Agricultural Water Management

journal homepage: www.elsevier.com/locate/agwat

How do farmers adapt to water scarcity? Evidence from field experiments[☆]

John Asprilla-Echeverria [a,b,c,*]

[a] Lund University, Faculty of Economic History, Scheelevägen 15, Lund 223 63, Sweden
[b] School of Social and Behavioral Sciences. Erasmus University Rotterdam, Mandeville Building, 17th floor. Burgemeester Oudlaan 50, Rotterdam 3000 DR, the Netherlands
[c] Center of Research and Innovations for Water, Sustainability and Circular Economy (AnfiBIO Sirculab), San Martín de Loba - Colombia

ARTICLE INFO

Editor: Dr Z Xiying

Keywords:
water extraction caps
water scarcity
adaptation
social institutions
sustainability
Colombia

ABSTRACT

This research is about how farmers adapt to water scarcity. Using experimental economics methods, field experiments were carried out in a region exposed to severe water scarcity in Colombia. Willingness of water users to cooperate in conforming to extraction caps, as a means of adapting to water availability declination was calculated. Two information treatment groups were implemented in order to assess water allocation decisions when: (i) the amount of water was reduced and (ii) time before aquifer exhaustion was announced. Extant literature on cooperation in common-pool resources (CPR) has focused on demonstrating to what extent resource users depart from egoistic attitudes. Alternatively, the sustainability of water resources requires more research to further understand cooperative behavior. Since the literature on water scarcity is classified in three orders, namely physical, institutional, and socio-political, behavioral dimensions are suggested as a subdivision of the social order. This, in turn, may help to operationalize strategies aimed at improving adaptation to all orders of scarcity. The quantitative results suggest that farmers are inclined to follow the cap. The main difference between the quantity and time treatments differs in that in the time treatments farmers allocate much more water to be consumed in the future, whereas in the former, they prefer to allocate more water to be consumed in the present. Adaptation options provide favorable inputs for implementing the Sustainable Development Goals, especially SDG 6, which is related to water use efficiency. Target 6.4 establishes that, by 2030, water efficiency and extraction sustainability should be accomplished. Thus, water policy interventions might benefit from this contribution. However, since success in water conservation programs might be difficult to achieve due to complexity in human-decision making, more research is needed to deepen our understanding of cooperation drivers in aquifer conservation.

1. Introduction

Despite the abundance and precision of current information on aquifers status (van der Gun, 2022), this type of data – commonly managed by governmental institutions – rarely flows to the communities that depend upon them (Margat & van der Gun, 2013). In effect, underground water availability data is currently assessed through satellite and underground monitoring of aquifer levels, but farmers ́communities do not have access to this information in a format they can readily use. Climate change is entering the aquifer overexploitation game as a new player (Damania et al., 2017), since droughts are becoming more frequent than in the past (UNWATER, 2023; Yuan et al., 2023); therefore, public environmental and water entities promote water conservation during droughts. Public entities usually stimulate the reduction of water extraction volumes by instructing users to consume less or save the resource. This information, however, lacks the necessary context and specificity, two features that play an important role in water extraction curbing adapted to ensuing water scarcity.

☆ I am indebted to Professors Bart van Hoof and Wim Hafkamp for their encouragement, comments and suggestions in preparing this article. The present work would have not been possible without the support provided by research scholarship grant number 783-2017 from the Colombian Ministry of Science and Technology. This project was also possible by the research project "Confronting the climate – water – biodiversity interactions: how rural communities can choose to become sustainable" (financed by FORMAS, the Council), DnR: F2023/.339). Similarly, the fine proof-editing and writing assistance work of my editor, Mr. Andrés Torres V., was very helpful

* Corresponding author at: Lund University, Faculty of Economic History, Scheelevägen 15, Lund 223 63, Sweden.
E-mail addresses: asprillaecheverria@essb.eur.nl, john.asprilla@ekh.lu.se.

https://doi.org/10.1016/j.agwat.2024.108783
Received 19 April 2023; Received in revised form 21 February 2024; Accepted 16 March 2024
Available online 17 April 2024

Although water scarcity has an important political dimension (Metha, 2007), from the perspective of its physical and social dimensions, it can be observed how climate change is motivating farmers towards strategies to face the challenge. In spite of the complexity of hydrogeological information, farmers certainly want to know more about the status of the aquifers they are exploiting. They need information not only about the effects of their extraction decisions, but also about the way to moderate these decisions as an adaptation to scarcity according to aquifers' statuses.

For instance, a complex relation exists between pumping, water tables and water stocks, which differs from one aquifer to another. Their interactions are usually studied by hydrogeologic engineering, the results of which should be readily available to user communities, so that they can benefit from it. Aquifer status variables may connect farmers with water as a resource worth to care of; however as a specific course of action for adaptation to scarcity, they might benefit from the more straightforward information provided by extraction caps, which simply tell how much water they should extract at each period of the year. This type of information actually embeds and digests the complexity of hydrogeological data. Digesting such an information to farmers is urgent since, agriculture demands more than 70% of extracted groundwater globally (World Bank, 2010). Farmers play a fundamental role in the need to curb water extractions in contexts of drought, and the capped extractions informed to them, should be carefully designed as a new generation of social rules.

Water extraction caps that consider water balance are essential to help to ensure the sustainability of groundwater resources. The extraction cap used in the present research was based on agricultural-related water consumption figures. Due to water scarcity and water footprints of consumption and production, water extraction caps by watersheds have been discussed as part of sustainability strategies and to address the paradox of water use efficiency gains (Grafton et al., 2018; Hoekstra, 2013). Models in which crops are simulated can be used to gauge the prospective impact on water-use efficiency and productivity of altering relevant attributes (Condon et al., 2004). Notwithstanding, provision of information to farmers is not observed as part of the explanatory variables for such an efficiency and search for cooperation. Sustainable water extraction as the expected result of cooperation, might constitute a step forward from the seminal research on whether individuals contribute tokens or not, to maintain or provide public goods or CPRs. This entails that if sustainable extractions guided by extraction caps are incorporated into integrated water resources management, cooperative behavior amongst water users, could be attained. As experimental rounds in this research were played, cooperative attitudes had behavioral dimensions worth to be considered to further understand cooperation. Conventional experimental designs study cooperation by measuring the number of tokens contributed to public goods (Fischbacher et al., 2001; Gächter, 2007; Keser and Van Winden, 2000). In this research, the concept of cooperation was operationalized as the disposition of farmers to conform to extraction caps to adapt to water scarcity.

Field experiments were conducted with farmers in which the extraction cap constituted a new rule to work with, based upon which they could build their own social institutions to cope with water scarcity. The used cap given to farmers was tested amongst two treatment groups: remaining time and remaining water amounts. Based on the reaction of farmers to these experimental conditions, a statistical test was applied to assess the probability of cooperation under water extraction capping.

1.1. Aquifer declines in the Colombian Caribbean

From a hydrographic standpoint, the Colombian Caribbean is classified as moderately to highly arid, which has determined that most of its urban and rural populations depend on groundwater and unstable surface sources (IDEAM, 2014). Some water wells in the department of Sucre have been found to decline at a pace of 17 m/year, which certainly poses a threat on aquifer stocks (Carsucre, 2003). In 2011, there were a total of 1788 active water wells over an approximate area of 645 km2. The extraction volume in the department of Sucre was 29.1 million m3/year in 1998, shifting to 41 million m3/year in 2022, thus having increased by 39%. The number of wells in agricultural lands in Corozal, Sampués and Sincelejo (Sucre) has increased by 60% in 20 years. Also in this department, the natural recharge rate of the main aquifer is 75 liters per second, while the extraction rate ranges from 1000 to 1200 liters per second (Carsucre, 2015), which clearly points at its intense overexploitation, vulnerability and progressive depletion (Carsucre, 2015). The total number of active wells in the department of La Guajira reached a historical record of 2230 by 2022, which is three times the number recorded 30 years before. In this same department, the average water tables were around 40 m deep at the end of the 90's, to reach 500 m deep in 2022.

1.2. Definition of the research problem

Water shortage in the Colombian Caribbean region takes place mostly between January and May. During this period, more than 100 municipalities of this region are usually declared to be undergoing drought every year. Ninety of them actually depend on aquifers for agricultural purposes and human consumption. Such scarcity can certainly be managed by reducing water extraction. Colombian governments have traditionally instructed citizens in these areas, to reduce water extraction volumes by just telling them to do so. However, at the core of the problem, there is little knowledge about the relation between information provision and the reaction of the farmers. Furthermore, farmers are seemingly reluctant to cooperate because they want to ensure water availability in the future. Under this setting, the current governmental approach to water scarcity does not see aquifers as CPR, in which extraction decisions depend on the actions and interactions of diverse social actors.

In this context, the current research problem states the lack of understanding about the effect of water scarcity information provision on extraction decisions, on the part of farmers and their willingness to cooperate. The present work was intended to understand farmers' adaptation to water scarcity under specific extraction capping suggestions.

Field experiments were conducted in the Colombian Caribbean region, with the participation of ten communities from the municipalities of Riohacha and Fonseca in the Department of La Guajira, which is featured by the existence of a relatively big desert area; and the municipalities of Guamal in the department of Magdalena, and Corozal (Sucre), a department whose agriculture is almost entirely dependent on groundwater.

The present article is organized in four sections. Section 1 corresponds to the introduction, which specifies the current approach to CPR management cooperation towards sustainable water extraction. In this sense, water extraction caps provide a very specific practical framework. Section 2 details the research methods, corresponding to field experiments and in-depth interviews intended to document the participants' water allocation preferences. A summary of the literature on the topic is included in the discussion. Section 3 describes the results. A necessary discrimination between empirical evidence of cooperation under extraction capping and social institutions and adaptation options was made. The results included a discussion of the intricacies of social and behavioral issues as they affect different aspects of adaptation to water scarcity. A discussion of the results and the corresponding conclusions are shown in the final sections.

2. Methods

The understanding of cooperative behavior of groundwater supply management as an adaptation to climate variability was addressed by using field experiments as the main research focus. The overarching parameter used to understand cooperation, was focused upon willingness to adapt to declining water availability. The mechanism used to operationalize that adaptation was based upon a water extraction cap.

Allocation of water units was not designed as if there were unlimited resources. Contrarily, the participants were challenged to appeal to their own capacity to think carefully on the intertemporal dimensions entailed by their water consumption. But this mental capacity was capped by a water limit mechanism. A suggested extraction cap was announced in every single round of the game, and players were free to conform and distribute it to the present - $W_{(p)}(t)$, water allocated to neighbors - $S_{(p)}(t)$, and water allotted to consumption in the future $W_{(f)}(t)$. The players could decide first to follow the capping rule or not, and then proceed to allot their selected amounts in each round to the present, future, and neighbors.

2.1. Sample selection process

In the first place, a list of 320 municipalities drawn from official reports on localities relying on aquifers and exposed to droughts was reviewed. With this information, phone calls were made to three environmental entities in the Colombian Caribbean region, asking for the list of neighborhoods in question. Two neighborhoods in each of the three municipalities were randomly chosen from the list. Local leaders or guides were suggested by authorities to facilitate access to the territories.

Six communities were randomly chosen and, upon visiting the places, some households were randomly selected with the support of local guides. Farmers and rural inhabitants who were actual users of local groundwater resources were invited to participate in the trials. The people were invited personally, so that face-to-face communication would make sure they dealt with frequent water extractions. Prior to recruitment, potential participants were given a brief explanation in which they were told that they would be making decisions in an "economic choice situation". They were also informed that the money they would earn depended upon their own investment decisions and those of the others in the experimental group. The most appropriate moment for running the field experiments was agreed with most of the visited farmers, who chose the weekends, since the associated opportunity cost was lower than in workdays. Additionally, during the driest days no harvesting activities took place. If the experiments were to be carried out during sowing, harvesting or commercial seasons, the risk of not getting well-thought data during the experimental sessions would be run.

Field experiments were run by setting up CPR action situations in the selected Colombian municipalities. During the experiments, the participants were asked to make decisions about water extraction. Relevant socio-physical information as if coming from external institutions was provided prior to decision-making, including data on water availability, time before aquifer depletion and neighbors' extraction rates. The implemented treatments are shortly described in Fig. 2–1; the types of treatments were designed by the type of information provided to challenge sustainable water allocation decisions amongst farmers.

The nature of the commodity at stake and the subject pool (Harrison and List, 2004) were strictly related to the research objective. Actual rural dwellers replaced the usual abstract commodities administrated when working with urban dwellers, since the latter use to have little connection with the extraction of groundwater resources.

The experimental settings included the following elements: participants, treatments, payment method and the water unit allocated to collective goods (Cassar and Friedman, 2004; Smith, 1992). These elements are explained below in Table 4 6. Experiments are frequently used to get a deeper understanding of natural resource use decision making and the factors affecting cooperation decisions (Anderies, J.; Janssen, 2013; Cárdenas, 2009).

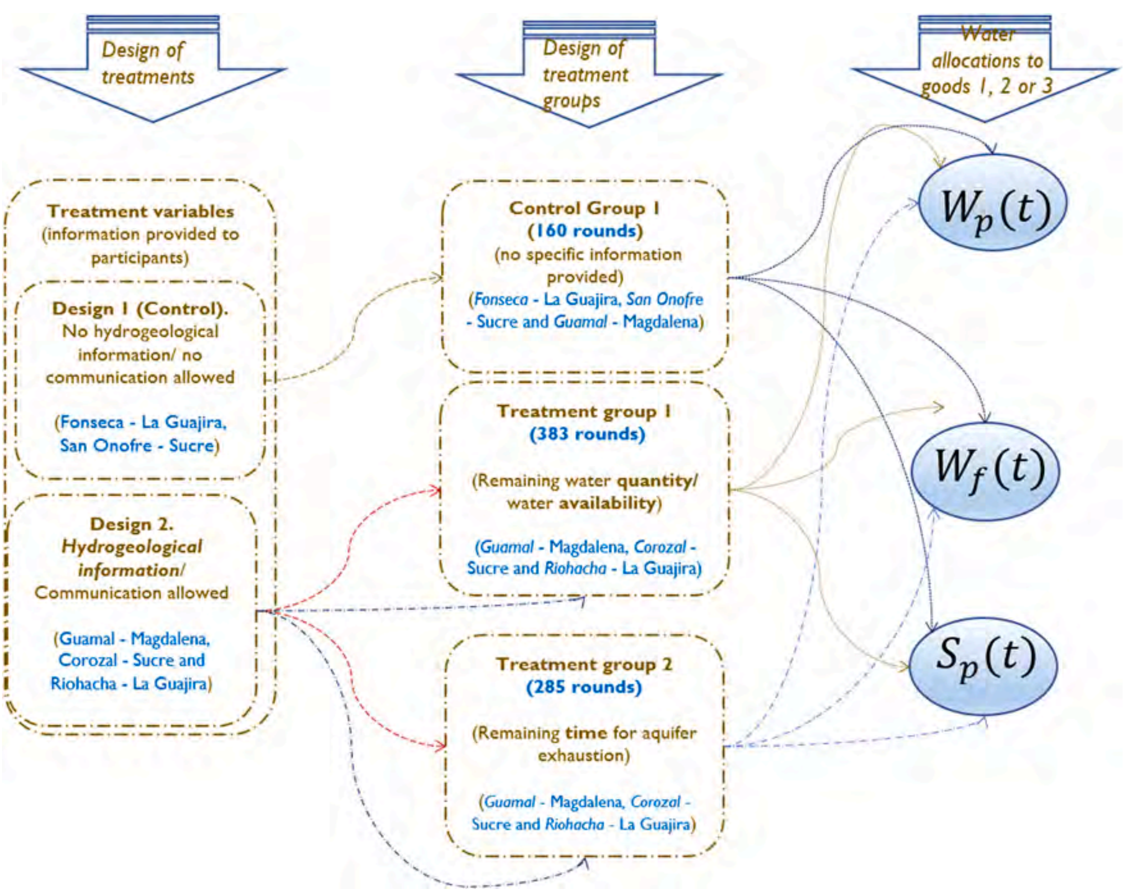


Fig. 2–1. Design of treatment information in water extraction games, Source: Asprilla-Echeverría (2022).

The nature of the commodity at stake and the subject pool (Harrison and List, 2004) were strictly related to the research aim. Actual rural dwellers replaced the usual abstract commodities administrated by urban dwellers having little connection with the extraction of groundwater resources. The experimental settings involve the following elements: participants, treatments, payment method and the water unit allocated to collective goods (Cassar and Friedman, 2004; Smith, 1992). Experiments are frequently used to get a deeper understanding of natural resource use decision making and the factors affecting cooperation decisions (Anderies, J.; Janssen, 2013; Cárdenas, 2009).

The data used in the analysis were generated in 668 experimental rounds across ten communities, wherein, participants generated an equal number of observations. Since each participant provided 4 observations per round, 2670 observations were collected during the games. That is, the participants were able to provide information on the extraction of water $W_{(p)}(t)$, $S_{(p)}(t)$, and $W_{(f)}(t)$. Total extraction (was compared to the cap), is considered to be additional data because farmers firstly decided whether to abide by the extraction cap and later on configured their specific allocation of water units to the three suggested pools. The participants played 12 rounds on average and none of them decided to quit the experimental sessions.

2.1.1. Treatment and control group

To assess the effect of water stock and flow information, two treatments were planned, explicitly one in which conversation between game players was at will, and another one in which conversation was not possible:

- *Design # 1. Base or comparative situation.* Farmers acting as players are not revealed the new hydrogeological information and are not allowed to communicate in determining how many cubic meters to extract. This resembles the control situation.
- *Design # 2.* Farmers are exposed to hydrogeological information regarding the water stock and flows in the aquifer system.

In the Fig. 2–1, a short description on treatment groups prepared in the four municipalities. In each municipality players were able to disclose their decisions on water allocations to ($W_{(p)}(t)$, $S_{(p)}(t)$ and $W_{(f)}(t)$).

2.1.2. Treatment group design

The treatment group players were allowed to access to different information contexts beforehand they made allocation decisions on water volumes. The input messages were presented to them using handouts.

- *Water treatment* groups. Farmers informed on the *remaining water* ***quantity*** in the reservoir in question (see Fig. 2–1)
- Time treatment groups. Farmers informed about the remaining **time** before aquifer exhaustion (see Fig. 2–1)
- In control groups, farmers were not provided with any information before decision-making.

In addition, additional information was provided to resemble alterations in meteorological conditions. The period (among the rounds) to announce the new information on raining or droughts was randomized.

2.1.3. Participants in the experimental games

During the experiments, the players expressed their decisions paper and pencil. Farmers who nowadays use groundwater resources were asked to attend the experiments. They were also communicated that the money they received depended upon their private water allocation decisions and those of the others in the groups.

The studied communities have had a long well-building and water extracting tradition according to their needs for agricultural and domestic activities. To this aim, they hire a local well builder. People install a ½ or 1-HP electric pump to carry out extraction, although occasionally, they install a manual pump. Thus, farmers and rural inhabitants have a local tradition of accessing underground water, extracting and consuming it almost in a daily basis.

In order to design and implement the experiments, a field setting resembling a microeconomic system or action situation was prepared, consisting of a set of agents and institutions through which they interacted. The agents were the individual participants in the local economy. Each agent had his/her own characteristics, including resource endowment (cash, time, wealth), information about others' preference endowments, technology (production functions) and preferred outcomes (Cassar and Friedman, 2004).

2.1.4. Payment method

The field experiments proposed in this research slightly depart from extant experimental design schemes. A connection is made between the aim of understanding cooperation in groundwater management and water extraction caps as an institutional mechanism, looking forward to the sustainable management of aquifers. I refer to this setting as a Voluntary Contribution Extraction Capped Game – VCeCG. The voluntary character comes from the participants' autonomous willingness to contribute, wherein the modification with respect to VCM lies in the physical context surrounding decision-making. Testing the extent to which individuals are willing to contribute to accomplish physically contextualized caps for water conservation is intended. The extraction caps are consequent with the need to adapt to water table declination. Thus, a socio-physical institutional setting is designed to understand how farmers adapt to these contextualized declinations.

2.1.5. Methods for data analysis

The methodology presented above refers to data collection. The method for data analysis is shortly described in the lines that follow. With this aim, the logistic regression model is summarized.

For some models, the dependent variable is usually a dummy one with values 1 if an event occurs and 0 if it does not occur. This refers to qualitative response models in which dependent variables fall on *m* mutually exclusive categories (Cameron, C. & Trivedi, 2005). Dealing with dummy variables with explanatory power on the right side of the regression is the common case. But what additional problems arise when this dummy variable appears on the left side of the equation? What is wrong with running Ordinary Least Square (OLS) on this research? After all, it is a feasible procedure (Baltagi, 2011). In the present case, we regressed the dummy variable (i.e., whether the participants are willing to fulfill the suggested water extraction cap or not) against variables such as well-depth, gender, time living in the community and others.

Table 2–1
Description of allocation activities and components of payoff function.

Type of allocation activity and components of payoff function	Earnings
$W_{(p)}(t)$	An individual payoff of 10 $COP.
$S_{(p)}(t)$	An individual payoff of 5 $COP (collective good)
$W_{(f)}(t)$	An individual payoff of 4 $COP (private benefit to be exploited in the future)
$\mu\sum S_{(p)}(t)$	Refers to the addition of the contributions made by every player in the game. *μ correspond to a collective gain received by all players upon the contributions of j players. This marginal payoff is equal to 0.2,*
θ	Refers to the endowment of water
ρ	Refers to the discount rate that each farmer *i* gives to his/her allocation to conserve water for the upcoming periods of time.
α	Corresponds to actual marginal resource consumption for farmers.
$\pi_i = \theta - \alpha\left(w_{(p)}(t)_i\right) + W_{(f)}(t)_i\left(\frac{b}{(1+\rho)^t}\right) + \mu\sum_{i=1}^{5} S_{(p)}(t)_j$	

Table 3–1
- Summary of number of observations and participants in experimental sessions.

Municipality – Department	Community	Number of rounds	Number of observations
Fonseca – La Guajira	Porvenir	50	200
	Villa Hermosa	40	160
Riohacha – La Guajira	La Trinidad	44	176
	La Reserva	44	176
	Los Ciruelos	44	176
	La Plazoleta II	44	176
Guamal – Magdalena	Paraquito	110	440
	San José de Paraco	55	220
Corozal – Sucre	Villa Luci	110	440
	Las Llanadas	126	506
Total observations		668	2670

The prediction from this OLS regression is interpreted as the likelihood to fulfill the cap. The problems with this interpretation are the following (Baltagi, 2011; Cameron, C. & Trivedi, 2005)):

i. We were predicting probabilities of fulfillment for everyone, whereas the actual observed values are 0 and 1.
ii. There is not guarantee that $\hat{y}_i$, the predicted value of y_i, is going to remain between 0 and 1. Furthermore, the OLS regression of y_i on x_i ignores the discreteness of the dependent variable and does not constrain the predicted probabilities between 0 and 1. In fact, one can always find values of the explanatory variables whose corresponding output would be outside the (0, 1) range.
iii. Even if one is willing to assume that the true model is a linear regression given by $y_i = x_i'\beta + u_i$, this will result in heteroskedastic disturbances (Baltagi, 2011).

A more appropriate model was the logit one, which specified that: $p_i = \Pr[y_i = 1|x_i] = \frac{\exp(\beta_1+\beta_2 x_i)}{1+(\beta_1+\beta_2 x_i)}$ and clearly ensures that $0 < p_i < 1$. Given that the current work considers two binary outcomes, the estimation was usually done by maximum likelihood, because the distribution of the data was necessarily defined by Bernoulli's model. If the probability of one outcome equals p, the probability of the other outcome must be $1 - p$. For regression applications, the probability p will vary across individuals as a function of regressors (Cameron, C. & Trivedi, 2005). There was no loss of generality in setting the values at 1 and 0 if all what is being modeled is p, which determines the probability of the outcome. A regression model is formed by parameterizing probability p, for it to depend on a regressor (vector x) and a $Kx1$ parameter vector β. Commonly used models take a single-index form, with a conditional probability given by: $p_i = \Pr[y_i = 1|x] = F(x_i'\beta)$, where $F(.)$ is the specified function. To ensure that $0 < p < 1$, it was natural to specify $F(.)$ as a cumulative distribution function.

Nonetheless, the interest lies in determining the marginal effect of a change in a regressor on the conditional probability that $y = 1$. A general probability model assumed to be continuous and representing change in the j_{th} regressor would be expressed as: $\frac{\partial \Pr[y_i=1|x_i]}{\partial x_{ij}} = F'(x_i'\beta)\beta_j$. As for any linear model, the marginal effect depends on point of evaluation x_i and varies with different choices of $F(.)$

3. Results

During the experimental sessions, reactions to socio-physical information were observed in water users' decision-making process. Due to the imperceptible nature of aquifers, the experiments were used to build a sort of three-dimensional image of aquifer stocks in the mind of the participants. Water users were able to see the connection between water flows extracted from round to round (i.e., along successive time periods) and the corresponding change in the underground water stock. As time passed, water stock declination could be observed as a signal of scarcity and a real issue that was worth understanding and managing.

The understanding of scarcity and aquifer stocks started by getting the participants acquainted with the aquifer reserves and their depletable nature. Less than 10% of the participants were familiar with the basic variables such as reserves, recharge level or the inclination of the aquifer system beneath, since this information was difficult to acquire and digest by users. Obliviousness on these topics reveals a sort of disconnection with the characteristics of the water source they depend upon. In this respect, the experimental sessions focused on making sure the participants were always knowledgeable on the availability of water resources. The common-pool nature of aquifer resources, in which the actions undertaken by different participants may yield productive or destructive outcomes on availability was explained as well. For this reason, the central piece of the analysis on outcomes was about *water availability* and this availability was utilized as an overarching variable across experimental sessions.

3.1. Descriptive statistics on participants

The Table 3–1 summarizes the data gathered during the experimental sessions. Participants representing community members have been living for a long time in their localities. Since they were familiar with groundwater extraction for almost all their lives, the experimental sessions were appropriate in terms of the field context.

On average, the farmers from the studied sites had been living at least half of their lives in their communities. As shown in Table 4–1 and Table 4–2 the mean age of the participants was 41, whereas the oldest ones were respectively 66 and 58 in the quantity and time treatment groups. The mean educational level corresponded to high school, i.e., 11 years of education. The most common activities among the participants were farming and merchandising of farm products.

3.2. Empirical evidence on cooperation under extraction caps

This section contains descriptive statistics about the current research findings. Quantitative and qualitative information were presented to provide evidence about the drivers of adaptation to water scarcity under an extraction cap setting. Special attention was paid to the dependent and explanatory variables captured through field experiments, questionnaires, and interviews. Water availability was bisected into two categories that were familiar to the participants, namely *time and quantity of available water,* which were tested as two overarching dimensions, denoting binding limits to water extraction from aquifers. Water allocation to $W_{(p)}(t)$, $S_{(p)}(t)$ and $W_{(f)}(t)$ was dissimilar for the water quantity and time before exhaustion treatment groups (see Table 4–1 and Table 4–2).

The descriptive statistics suggested that when farmers were informed on time before aquifer exhaustion, they had a more conservative behavior. In the water quantity treatment group, farmers allocated a maximum quantity of 5000 m^3 to the present (see last column in the first row in Table 4–1), whereas in the time group, they allocated a maximum of 1500 m^3 per round to the same pool (see the last column on the first line in Table 4–2). As it can be observed, the quantity treatment group exerted more pressure on their aquifer resources, as can be seen in the minimum amount of available water left by this group. Maximum well depth was 170 m, which implies a great building effort. Similarly, water users may form an image of how far the water table was from the surface, and how much deeper or shallower their wells were with respect to those of the other group members. Average earnings were almost five times the minimum salary hourly wage in Colombia, that is, $19,000 per participant, were paid in cash.[1]

With respect to water allocation to future consumption, visible contrasts were also found between the quantity and time treatment groups. In the first group, the maximum quantity allocated to this pool was as big as the one allotted to the present. In the time treatment group, the maximum allocation to the future was almost 30% greater than the one assigned to present consumption. The standard deviation values of the present and future allocations were higher in the quantity treatment group. This showed greater variability in the decision-making process for this group in terms of how to allocate the available water. The participants' water allocation preferences were activated by the information contrast between the quantity and time groups.

Some cross-tabulation descriptive statistics were added to contextualize the current results. For instance, in the distribution of the decision to abide by the extraction cap was presented by gender. Among those that decided not to abide, 54% were women and 46% were men. Among the females, 13.68% preferred not to follow the suggested rule and, contrarily, 86% preferred to follow it. Among the men, the proportions were 11.4% and 88.6% respectively.

In Table 4–4 and Table 4–5, the cross tabulations were focused on well depth and time preferences. It can be hypothesized that the farmers benefiting from shallow aquifers might be less inclined to allocate the most water to the **future**. Although this section does not provide any inferential analysis, some descriptive clues can be shown. Sixty three percent of the farmers living in territories where aquifers are shallow (less than 20 m deep) preferred not to allocate the most water to future consumption, while 38% of them did so. Among the farmers living over deeper water-wells, slight differences could be observed between the two preferences (66% and 34%, respectively). The situation changes when well-depth is shifted. For greater than 40-meter well-depth reference points, 80% of players preferred not to allocate the most water to the future and only 20% did so. In turn, these figures were 41% and 59% for those relying on less than 40 m deep wells.

With respect to water allocation to the **present**, this was the preference of 50% of the farmers relying on more than 20-meter-deep wells. For more than 40-meter-deep water-wells, a clearer preference for the present was- observed in 63% of the participants, as it can be seen in Table 4–5.

3.3. Water quantity treatment group results

The empirical data suggests that farmers adapt to water scarcity differently when exposed to the limits of time and water quantity, as shown in Graph 3–1 and Graph 3–2. Quantitative information on adaptation was firstly discussed on the preferences revealed by the participants when faced to declining water amounts. In this information treatment group, the data suggest that farmers were willing to abide by extractions caps, and only in the first two rounds, this cap was exceeded. The adoption of an extraction cap, as a guiding rule for water extraction decision-making, suggests that it is possible to reach a stable cooperative behavior. The observed, smooth declinations of water allotted to the present, the future and neighbors show that farmers can consciously decide on how to adapt to water scarcity.

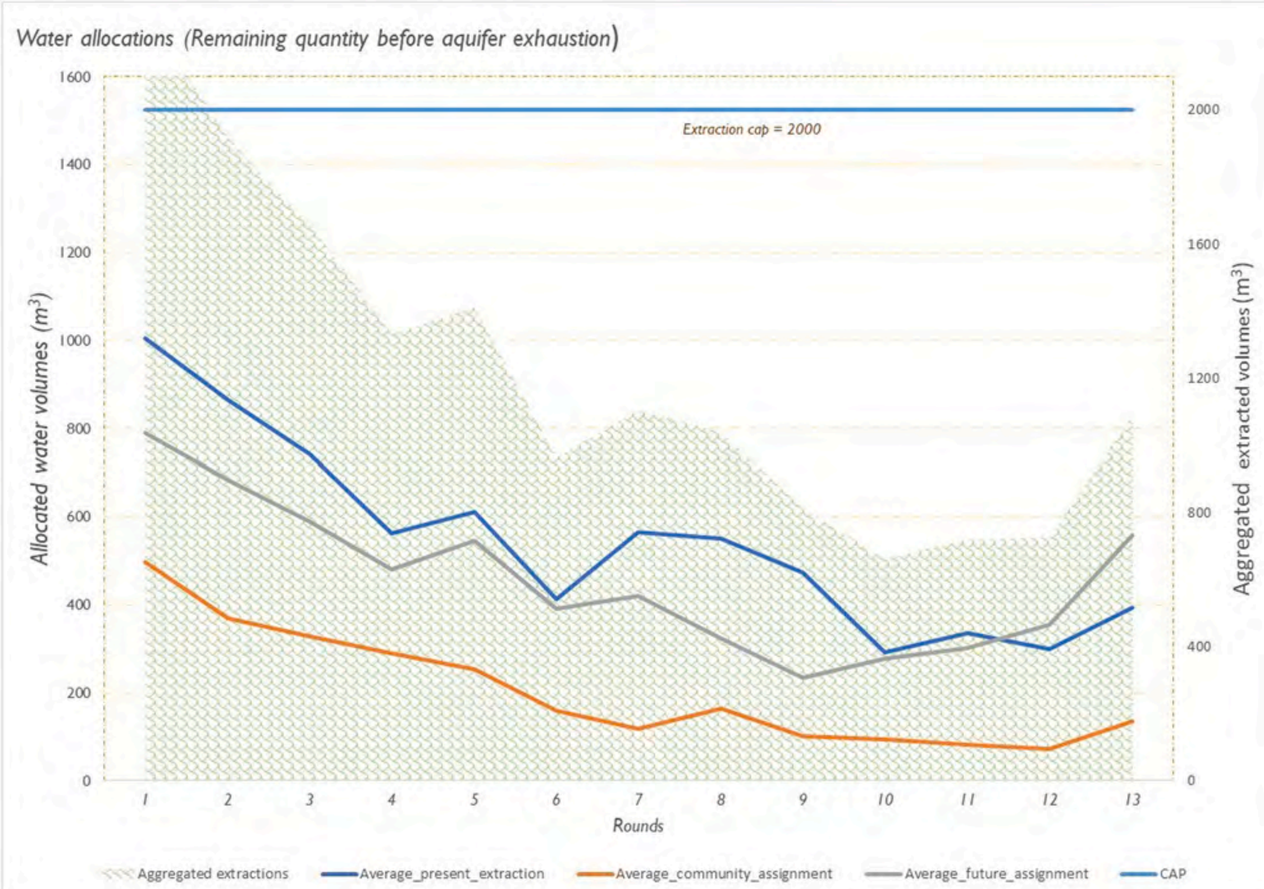
In order of preference, farmers adapted by allocating more water to the present during most of the rounds, while allocation to the future was in second place. Allocation to neighbors exhibits a preference for non-egoistic behavior. During half of the decision-making periods, farmers allotted around 30% more water to the present than to the future. At the beginning of the second half of the rounds, farmers exhibited sudden reactions in amounts of their declinations; they almost doubled their allocations to the present. However, at the end of the periods, the allocation to the present declined with respect to the future, which ended up playing a dominant role. Thus, dynamic reactions to water availability declinations instead of static or naive feedback were observed during the three segments of the $W_{(p)}(t)/W_{(f)}(t)$ trade off (see Graph 3-1)

Special attention was given to the last segment of $W_{(p)}(t)$ and $W_{(f)}(t)$, in which, on average, the latter surpassed the former. In the last segment different issues came to farmers ́ minds, but overarching fact referred to the situation in which the aquifer water availability was much scarcer, and few time periods existed for consuming this water. So, a precipitous decision to think of more in the future appeared. Why did that occur? Was it the late recognition that the future exists? Did the farmers react late to allocating water reserves to face looming threats of scarcer situations and shortages? Was it a sort of *drowning kick reaction* to what was almost exhausted? Farmers stated that since daily life activities are developed in the present, preference for higher allocations to this good $W_{(p)}(t)$ were stated (*present bias*). However, this argument may fall short when observing the distance between $W_{(p)}(t)$ and $W_{(f)}(t)$ in Graph 3-1.

Despite of not presenting any metric that measures a fair or close relationship between allocations, present to future, opportunities exist to express that assigning an average 1.3 ratio present/future, might result as a conservative water allocation in favor of the future. That is, the future was borne in mind as the time passed and as water users were making intertemporal decisions. Nevertheless, farmers may inquire about why trusting in an upcoming future when uncertainties exist. Uncertainty on water availability comes from weather conditions, risks of food insecurity, pandemic situations like Covid-19 and other sources of risks and uncertainties. Perhaps, the probabilities that farmers assign to living in the future with some water units, are permeated by the fact that dealing with tough situations in water scarcity is easier when scarcity is part of the landscape. So, facing an extreme situation on scarcity, does not discourage farmers to have some belief in the future.

The intertemporal water consumption trade-off implies an intention to safeguard some water flows for the future. Ignoring future consumption not only threatens the sustainable availability of this vital resource, but also might be extremely costly when it comes to guaranteeing its affordability. Choosing to follow a sustainable groundwater extraction path is a matter of intertemporal choice between immediate or distant sacrifice. Consumers seem to be of two minds about intertemporal consumption: when sacrifices are distant, patience predominates (Laibson, 1998). The current experiments required the participants to initiate the adoption of immediate sacrifices through limiting maximum water amounts consumed along sequential periods. More suggestively, extraction caps allotted to the present, future and neighbors went beyond willingness to cooperate with a CPR. Delaying consumption by allotting high water volumes to the future reveals concern about tomorrow. During the first half of the extraction periods (first 7 rounds), the average allocation to future consumption represented 70% of the present one. This may be a sort of adaptation based on *smooth patience preference* instead of abrupt changes in extraction paths. Perhaps the provision of information on the hydrogeological context, interactions with neighbors and sustainability indicators led by extraction caps were not capable of activating a sharp differentiation between present and the future. Indeed, reserving high water volumes to be consumed in the future suggests that farmers prefer to reserve for tomorrow similar levels of satisfaction to those they have in the present.

[1] Field experiments were chosen as the principal research method because it does better in resembling the real-life situation of microeconomic settings. In microeconomic contexts, cooperative behavior can be incentivized by balancing the costs and benefits of decisions made on water allocations. For this aim, the money earned reflected the benefits and costs that water allocations entailed.



Graph 3–1. Water allocations (remaining quantity before aquifer exhaustion), This graph depicts water extraction volume preferences. Field experiments were used to collect data. The horizontal axis represents the rounds in which the participants made their decisions. The vertical left axis shows average water volumes allocated to each one of three pools (present - $W_{(p)}(t)$, future - $W_{(f)}(t)$ and neighbors - $S_{(p)}(t)$). The right vertical axis represents the aggregated water volumes, which were compared to the 2000 m^3 extraction cap. The data correspond to the remaining water amount before aquifer exhaustion treatment group. Source: author's elaboration.

Thus, this intertemporal rationale indicates a certain level of sacrifice in the present, in favor of a corresponding satisfaction in the future.

The willingness to incur, in the short or the long-term, marginal consumption sacrifices may change depending on water abundance or scarcity. Marginal conditions may be relevant when comparing farmers' willingness to face sacrifices in the near and distant future. Adaptation to sacrifices in groundwater consumption on the part of groups accustomed to plentifulness or scarcity may be at odds. For instance, water "carries important aesthetic, social status, and recreational affordances, which are deeply ingrained in upper middle-class lifestyles" (Harlan et al., 2009). Similarly, the maintenance of property value and the importance of a healthy and attractive garden as a symbol of economic status and house values within a neighborhood are all more important than conserving water (Harlan et al., 2009; Spinti et al., 2004). On the other hand, farmers living in drought-exposed regions in developing countries might exhibit a different rationale. Switching human minds when facing lesser availability of a given resource is not a straightforward issue, especially when comparing a community that departs from abundance to one that already starts from a condition of scarcity.

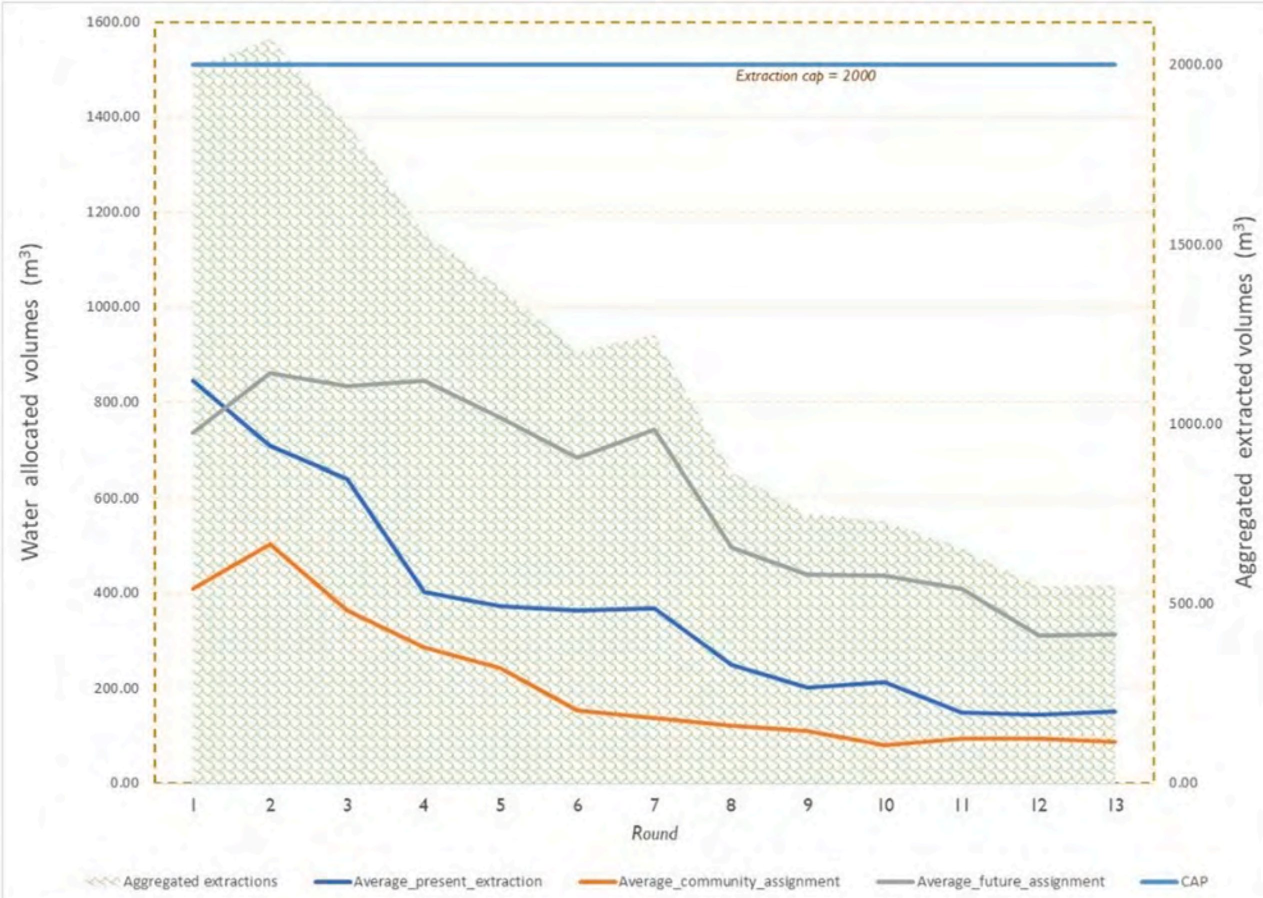
One may inquire which type of farmer is more able to postpone his/her accustomed water extraction level just to facilitate aquifer recovery. Delaying a customary extraction level would require a mental process to get rid of habits. Similarly, requesting water users to reduce extractions requires certain knowledge and information on current extraction levels. Without approximate extraction volume information, there are no reference points to compare with since real sustainability concerns deserve gauging basic variables such as extraction volumes.

The path of allocation to present, future and neighbors is closely related to intertemporal decisions on preferred water amounts, which, in turn, revealed intertemporal trade-offs.[2] For instance, farmers who plant water-intensive crops were asked about key water adaptation indicators such as water volumes applied to crops $(m^3|ha)$, land productivity $(Kg|ha)$ and the effect of irrigation on crop yield $(Kg|m^3)$. However, these indicators were unknown, as reported by 90% of the interviewed farmers.

3.4. Time treatment group results

On the other hand, different incentives may promote cooperative behavior when users observe water declination, and they are faced with information on the remaining time before aquifer exhaustion. Information on time before aquifer exhaustion, led the farmers to declare their water allocation preferences by allotting more water to the future than to the present, or for their neighbors. On average, farmers allocated

[2] In the annex section a note on valuable qualitative information collected during the water quantity treatment group is included. This information was part of the narratives on the reasons on water allocations to the present and to the future.



Graph 3–2. Water allocations (remaining TIME before aquifer exhaustion), In this graph, the preferences on volumes of water extraction are depicted. Field experiments were used to collect data. The horizontal axis represents the rounds in which participants made their decisions. The vertical left axis shows average water volumes allocated to each one of 3 pools (($W_{(p)}(t)$, $W_{(f)}(t)$ and $S_{(p)}(t)$). The right vertical axis represents the aggregated water volumes, which were used to compare with the 2000 m^3 extraction cap. The data shown correspond to the TIME before exhaustion treatment group. Source: Author's elaboration.

almost two times more water to the future than to the present (see Graph 3–2).

The likely reasons for this preponderance of the future over the present may come from farmers' incentives and mental considerations in times of water source exhaustion. Since the time dimension is more familiar to water users, this variable may activate a preference for more patient behaviors. Time is embedded in daily life issues. For instance, growing crops takes time. Sowing and harvest periods are planned according to the expected time of the rainy seasons. Deciding the moment for increasing the cattle horde size is a matter of planned timing. The age of children is born in mind to wait for their support in farming activities. In accomplishing production goals, farmers recognize the time taken by nature to yield. While some water can be gathered from partners or neighbors, aquifers themselves cannot be forced to yield over their inflow rate, just as you cannot harvest any fruit, vegetables, tubers, or cereals before they have completed their natural growing cycle. Specifically, stocks take time to change because flows take time as well (Meadows, 2008). The weekly or monthly mass gained by plants cannot be accelerated as wished. Meanwhile, a crop's yield stock can be sped up and accumulated by buying products from other places where harvest comes first or through imports. However, in these situations the productive flows take time to increase. In any case, producers may have incentives to accelerate productivity by investing in genetically modified seeds or other adaptive investments. But the productive flows take time, and it is up to nature, not the producer, to do that task.

Being aware of this situation entails the need to smoothly adapt to changes. Instead of big leaps in average allocations per period, flat declinations were observed from the beginning to the end of the games. At the middle of the experimentation time, an abrupt shift in the declining trend was observed, resulting in the steepest declination of all. For allocations to neighbors and the present, there were episodes in which a tendency to repeat prior allocations is observed. This might be an adaptive strategy to manage uncertainty or to gauge/analyze/understand the issue of extraction rate, which might be called the *experience heuristics* when uncertainty, indecision and lack of knowledge become evident.

Some differences between the quantity and time models are presented:

- o Time is more implacable than quantities. For instance, reductions in water quantities can be related to reductions in crop production. Farmers might plea or negotiate with neighbor farmers who might have experienced a higher water use efficiency and have gotten greater yields. However, since time for aquifer exhaustion affects every farmer similarly, fewer options exist to extract water to produce in that specific territory. Thus, over time the water stock reductions will affect each farmer.
- o Marginal changes in water allocation to the present are less pronounced in the water quantity context, with respect to the time before the aquifer exhaustion situation.
- o In both treatment groups, the acceptance of extraction caps was swift. The main difference between them refers to the good to which water is mostly allocated, since in the quantity context farmers

preferred to allocate more water to the present, while in the time situation, they allocated much more to the future.

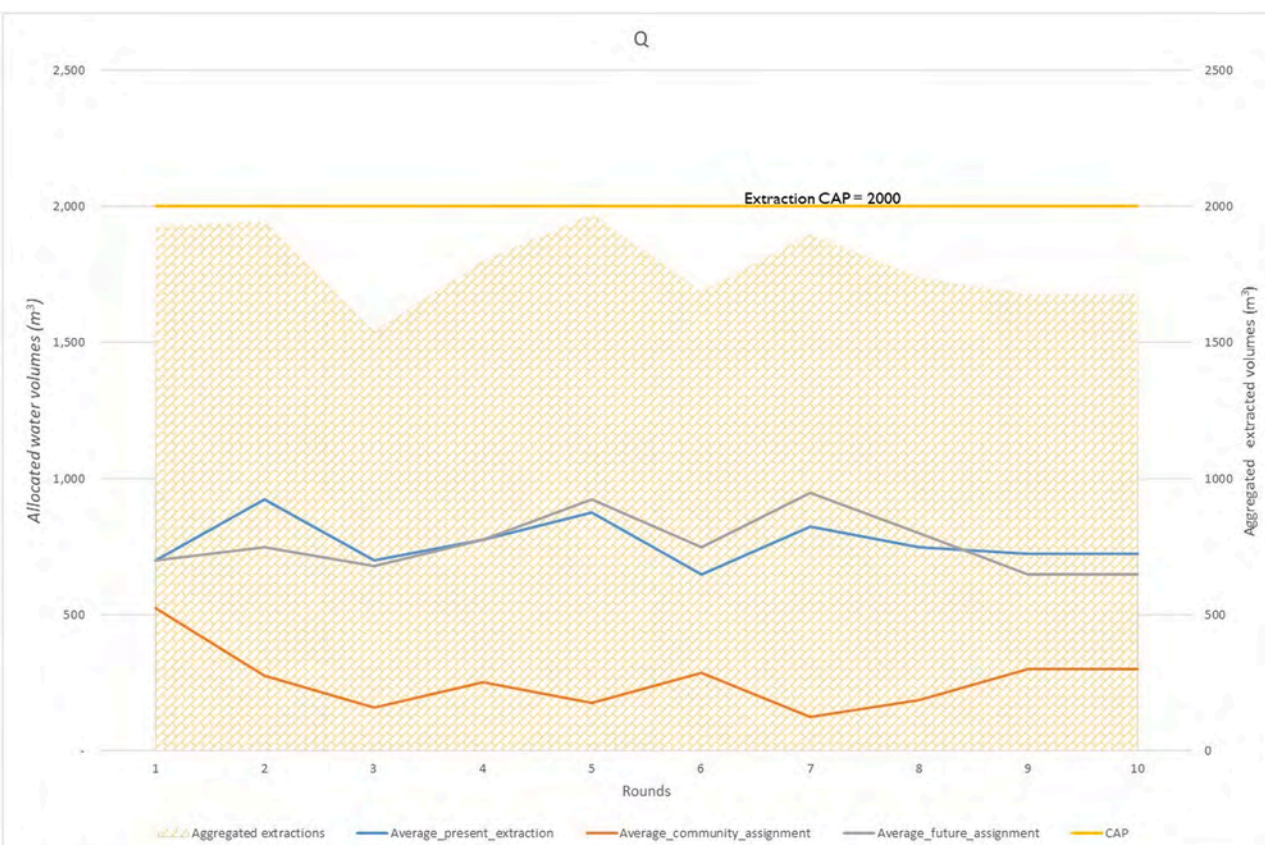
3.5. Control group results

In reference to the control-group water allocations, the Graph 3–3 presents the resulting data. Following the experimental design in Fig. 2–1, on average the aggregated water allocated was closer (1800 m^3) to the suggested cap (2000 m^3). Despite this amount is less than the cap, it is greater than the amounts allocated in the treatment groups (see Graph 3–1 and Graph 3–2.). In addition to this, the preponderance of water allocations to the present or to the future is not stable. At the beginning and at the end of the rounds, the present prevails, while in the middle, the allocations to the future were greater or similar among them. The impediments of holding non-binding communications amongst control-group members, may generate more uncertainties, which may be revealed in the instability of allocations. Since farmers of this group were not acknowledgeable about the remaining water or time for exhaustion, they were not able to have a closer idea on the magnitude of the problem as occurs in the reality. A pattern worth revealing refers to the relevance of neighbor farmers in allocations of water. No matter if the farmers are provided with hydrogeological information or not, the intention to share water with all is kept. Thus, it can be said that farmers are naturally willing to share water, but this behavior does not guarantee that the aquifer remain for future water extractions.

4. Discussion

Adaptation to climate-change in water-related issues is multifaceted and has intricate dimensions that are important to investigate. By focusing on a severe blue-water scarcity region in Colombia (Mekonnen and Hoekstra, 2016), a contribution was made to the dialogue on how farmers adapt to water scarcity. The setting for the understanding of adaptation strategies was demarcated by the social institutions and the working rules observed in the field and the limits imposed by nature. The latter was incorporated because acting in institutional settings should not be freely done if the necessary physical conditions are not locally met in terms of aquifer stocks and flows. For this reason, the central piece of analysis for this research was about water availability and, consequently, about water balance. Although different rules and institutions to sustainably manage aquifers can be designed, the physical limitations of water balance governed by nature impose binding limits to water extraction. Thus, a socio-physical setting is proposed as a background resembling water users' mental map. Instead of abstract situations in which participants in experiments are asked to allocate tokens (Cardenas et al., 2011; Gächter, 2007), the nature of the commodity at stake and the subject pool (Harrison and List, 2004) in this research were strictly related to the research aim on water avallability and ensuing caps.

Extraction caps have been suggested to address water scarcity and the paradox of water use efficiency gains (Grafton et al., 2018; Hoekstra, 2013). In addition to this, and to the best of our knowledge, field experiments on water extraction caps have not reported in the literature. Closer models to capped games refer to threshold games and usually respond whether thresholds (ceteris paribus) influence increased



Graph 3–3. Water allocations in the Control Group situation, In this graph, the volumes of water allocated by the control group members are depicted. The horizontal axis denotes the rounds played by participants. The vertical left axis presents the average water volumes allocated to each one of 3 pools (($W_{(p)}(t)$, $W_{(f)}(t)$ and $S_{(p)}(t)$). The right vertical axis represents the aggregated water volumes, which were used to compare with the 2000 m^3 extraction cap. Source: Author's elaboration.

contributions (Ledyard, 1995). The evidence suggests that increases in thresholds increase contributions, together with the probability of not reaching the target (Ledyard, 1995). Models on extraction quotas games (Pfaff, et al., 2015; Velez et al., 2009) are also reported as similar to quantity limits.

The extraction-capped game designed for the time versus water quantity treatment groups was useful to capture intertemporal time preferences. Time group allocated more water to the future and the latter preferred to assign more to the present. While different explanations of this pattern may be considered, the results suggested that referring to time, activates a deeper cooperative behavior towards water conservation. Perhaps dealing with water amounts makes it easier to figure out how to fetch water, since farmers who have lived in the territory for 40 years on average, can be said to have developed multiple adaptations to remain in it. Thus, in periods of water scarcity or declining water tables, they surely have conceived alternatives to afford their necessary water supply with some support from governmental agencies. Instead, dealing with time before aquifers get exhausted can be taken more seriously, because time might be more stringent. In other words, there might be substitute water sources, but the time of an event cannot be substituted. If there are any beliefs on a delayed time for aquifer exhaustion, this was permeated by the probabilities, guesses or hunches farmers construct, based on their long experience in managing and progressively adapting to water table declinations for generations. Thus, the contrasting forces that operate between reactionary and anticipatory behaviors (Apraku et al., 2008) seem to be reflected in the quantity and time contexts, respectively. Despite being knowledgeable on qualitative deterioration of aquifer conditions, farmers still believe that the future waits ahead, which is the reason why more water units were allocated to it. The cap played a role in suggesting that changing the social decision-making on water extraction might be a useful working rule, aimed at adapting to the limited character of aquifer systems.

The limited nature of aquifers was not fully addressed by users and well builders. In extraction activities, different incentives and information exist to address borehole management. Water well owners and builders have different perspectives on groundwater access and extraction stages. Private well builders and engineers in charge of the maintenance of public water wells have the perception that engineering solutions might always be found to dig deeper to find underground water. In doing so, water shortage is tackled simply as a physical problem, i.e., a first order scarcity (Mehta, 2007; Wolfe and Brooks, 2003).

Just as central managers, the role of environmental authorities might be more productive if they release the technical information as an input for better adaptation to scarcity. Hence, the current predictions do not really indicate the seriousness of the water scarcity situation (Apraku et al., 2008). The present work suggests that useful hydrogeological information be provided to water users through the conventional channels. Farmers are not expected to be as knowledgeable as a hydrogeologist, but to learn how to use aquifer status data to raise their awareness on the evolution of this resource in time and space.

Nonetheless, communities living with physical scarcity usually devise progressive adaptive strategies. In the status quo, farmers adopt a series of rules to adapt to water scarcity conditions. It was found the farmers implement social rules of access to water, rules of interaction inside the communities and rules of adaptation. When water becomes scarcer, sharing water amongst neighbors is a norm and similarly, when water wells become unproductive, farmers organize themselves to build community boreholes to deal with the high costs of its construction. When water quality issues arise, farmers stop extracting in the present, hoping it becomes cleaner in the short term. When dealing with declining water tables and inaccessible water reserves, neighbors expect some entrepreneurs do the job of building a new well. Then, the costs of information on availability, quality, and productivity of the new wells is reduced to almost zero for the other farmers since this information is shared amongst the community of farmers. The adoption of new cropś varieties is normally accepted if it comes from external governmental or non-governmental agencies able to fund the transition to more productive or resistant crops.

In this respect, social institutions and behavioral regularities operate and provide valuable inputs for managing physical water scarcity by addressing social, cultural, and behavioral issues. This represents a departure from the classical supply-side approach (Griffin, 2006) and top-down regulations (Pahl-Wostl and Knieper, 2014) that govern water resources. Behavioral and institutional aspects were drawn from the narratives and quantitative data resulting from the current experimental sessions and in-depth interviews carried out with water users, environmental authorities, borehole drillers and engineers in charge of borehole maintenance. Like borehole technicians and engineers, in the context of water table declination, farmers usually think of aquifers as unlimited resources. So, there is a tendency to ask themselves: Why measure something that will not end during life on earth? This propensity might be named the unlimited stock belief. When farmers are asked to reduce extraction and implement activities to increase inflow (recharge), this requires a paradigm change. Thus, farmers are not familiar with increasing inflows to replenish aquifer systems, which might represent an outflow routine effect.

These and other types of behavioral dimensions referring to risk management, routines, beliefs and perceptions are still under construction in the literature on behavioral and institutional economics. (Singh et al., 2018) highlight the relevance of risk perception on the adoption of strategies to adapt to scarcity in India. Similarly, the social perception of the meaning of scarcity was stressed. The role of memory and the consequences of past scarcity events with respect to recent ones played key roles in adaptation to scarcity and, particularly, exhibited a bias toward recent events. All the coping strategies employed by communities for water scarcity adaptation in Ghana were mainly reactionary in the short term (Apraku et al., 2008). Since scarcity is understood from physical, institutional, economic and behavioral standpoints, alternative solutions to observed water table declination go beyond engineering and supply-side solutions, as stressed by (Singh, Ch.; Osbarh, H. & Dorward, 2018; Wolfe and Brooks, 2003). More research is needed to support farmers's ability to adapt to the physical and socio-institutional facets of scarcity. In this research, a subdivision of the orders of scarcity can be drawn, thus facilitating the placement of the behavioral side of the problem. The first, second and third orders of scarcity were respectively the physical (engineering), economic (institutional) and socio-political ones (Mehta, 2007; Wolfe and Brooks, 2003). This allows placing the behavioral dimension in the social order of scarcity, which may help to operationalize improved strategies for adapting to water availability and quality declinations. There exist also relevant ecological dimensions integrated via recharge of aquifers dynamics announced to players in the experiments, which go beyond the scope of this research.

5. Conclusions

This article was designed for presenting the results on how farmers adapt to water scarcity. Framed field experiments were run to collect quantitative data on the decisions made by farmers when they were exposed to reductions in water availability. Time and water quantity treatment groups were prepared to test their effects on water allocation as limited by suggested extraction caps. Quantitative and qualitative analysis of data and information were carried out. Behavioral regularities and social institutions were drawn from the quantitative data and graphics and the narratives expressed by the players after the experiments.

The setting for the understanding of adaptation strategies was demarcated by the limits imposed by nature. For this reason, water availability as a physical limiting factor for water extraction was used as an instrument to connect allocation, decision-making and intertemporal consequences for adaptation. Thus, limited availability under time and quantity limits pushed the farmers (players) to decide whether to cooperate or not in water conservation. Thus, the individuals who cooperated better were adapting to water scarcity. More precisely, the farmers informed on time before aquifer exhaustion, revealed greater awareness about the possibilities of cooperation. Contrarily, in the control group situation, farmers allocated much more water to all uses and the cap volume was reached in most of the rounds. While in the time and quantity treatment groups, the aggregated water volumes declined through the time (rounds), in the control group this amount averaged 1800 m3 (close to the cap). It can be said that the communication amongst farmers on how to manage remaining stocks, and, similarly the hydrogeological information play a key role in incentivizing the cooperative behavior under extraction caps contexts. Since the stability of cooperation was part of the research aims, providing quantitative information to farmers on extraction decisions and the remaining time of aquifer availability is suggested as a key factor to more effectively address the adaptation to water scarcity.

This results suggest that in any water management program aimed at incentivizing water extraction reduction, time related strategic information should be clearly designed and delivered to community users. In addition to this, behavioral dimensions were found as key aspects of water allocation through the time, which are broader than forthright adoption of regulatory approaches.A couple of behavioral regularities are highlighted:Unlimited stock belief and drowning kick reactions. With respect to the stock belief, it demands making the figures on aquifer variables as a common knowledge to farmers. In doing this, the belief in the existence of infinite groundwater pools may help to reduce consumption rates. Secondly, in respect to the drowning kick regularity, this entails that farmers tended to allocate more water to the future at the end of the experimental sessions. When an aquifer is nearing depletion and this information is made common knowledge, many water users may commence to believe that time is showing the exhaustible nature of the CPR, and they may start to extract less water in the present to help to ensure that the total resource may last longer in the future. This implies that water users are confident that the water stock left in the pool for the future is not consumed by many others in the present. A credible and reliable information system on CPR status is essential to convince water users to acknowledge and respect the water budget status. All these and other behavioral issues are valuable as a means of making adaptation to scarcity more feasible and stable.

Behavioral issues in adaptation to scarcity, have implications in pursuing SDG 6 on water use efficiency. Rather than water volumes, providing information to farmers on the time before aquifer depletion may help in attaining such an efficiency, especially in regions exposed to droughts and water scarcity. This research has several limitations. Different extraction cap levels could not be tested due to limited funds to pay the participants. Varying the cap figure might generate different cooperation decisions as well. The types of rules and institutions needed to be better adapted to scarcity conditions led by stringent extraction caps would provide valuable insights. Further research is needed on the social institutions and the water management stages in which allocation decisions transpire. The research agenda includes the effects of altering the extraction cap level, comparing more territories, testing the effects of multiple crops adoption, understanding the stability of cooperation and the role of environmental authorities' behavior as part of the promotion of sustainable water use and consumption.

CRediT authorship contribution statement

John Asprilla-Echeverria: Writing – review & editing, Writing – original draft, Validation, Software, Resources, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

Annexes

Table 4–1. Descriptive statistics for **remaining water quantity** treatment group

Variable	*Obs*	*Mean*	*Std. Dev.*	*Min*	*Max*
Extraction in the present (m^3)	*384*	*530,62*	*635,78*	*0*	*5.050*
Allocation to neighbors (m^3)	*384*	*195,15*	*232,16*	*0*	*1.500*
Allocation for the future (m^3)	*384*	*516,85*	*744,63*	*0*	*5.500*
Available water (m^3)	*384*	*41.098*	*22.501,18*	*-27.825*	*80.000*
Age (years)	*383*	*40,56*	*11,939*	*14*	*66*
Number of children	*383*	*2,4*	*1,5*	*0*	*7*
Years of education (years)	*383*	*11,360*	*3,28*	*5*	*17*
Monthly income ($)	*335*	*770.447,8*	*745.644,7*	*0*	*2.500.000*
Time living in the community (years)	*383*	*33,407*	*17,251*	*1*	*66*
Well depth (m)	*383*	*42,365*	*50,425*	*0*	*170*

Source: Authoŕs calculation using Stata 17

Table 4–2. Descriptive statistics for **remaining TIME** treatment group

Variable	*Obs*	*Mean*	*Std. Dev.*	*Min*	*Max*
Extraction in the present (m^3)	*281*	*375,893*	*349,45*	*8*	*1.500*
Allocation to neighbors (m^3)	*280*	*206,107*	*212,791*	*0*	*1.000*
Allocation for the future (m^3)	*281*	*616,55*	*567.19*	*0*	*1.940*
Available water (m^3)	*281*	*39.940,83*	*22.696,53*	*-6.315*	*80.0*
Age (years)	*281*	*41.74*	*12,44*	*17*	*58*
Number of children	*281*	*2,5*	*2.1*	*0*	*8*
Years of education (years)	*281*	*9,3*	*3.9*	*3*	*16*
Monthly income ($)	*257*	*744.630,4*	*71.6013,2*	*0*	*2000.0*
Time living in the community (years)	*281*	*29,53*	*19.9*	*1*	*58*
Well depth (m)	*281*	*74,64*	*53.67*	*5*	*170*

Source: Author's calculation using Stata 17

Table 4–3. Crosstabulation between the willingness to abide an extraction cap and gender

	Gender		
Follow CAP	0 (Female)	1 (Male)	Total
0 (No)	26	22	48
	54.17	45.83	100
	13.68	11.40	12.53
1 (Yes)	164	171	335
	48.96	51.04	100
	86.32	88.60	87.47
Total	190	193	383
	49.61	50.39	100
	100	100	100

Source: Author's calculation using Stata 17

Table 4–4. Crosstabulation between preferences for the future and well-depths

	Shallow_aquifer?					
Preference_for-future	>20 m depth	>40 m depth	<20 m depth	<40 m depth	Total (20 m depth)	Total (40 m depth)
0 (No)	150	80	98	168	248	248
	60.48	32.26	39.52	67.74	100	100
	65.79	80.00	62.82	59.15	64.58	64.58
1 (Yes)	78	20	58	116	136	136
	57.35	14.71	42.65	85.29	100.00	100
	34.21	20.00	37.18	40.85	35.42	35.42
Total	228	100	156	284	384	384
	59.38	26.04	40.63	73.96	100	100
	100	100	100	100	100	100

Source: Author's calculation using Stata 17

Table 4–5. Crosstabulation between preferences for the present and well-depths

	Shallow_aquifer?					
Preference_for-present	>20 m depth	>40 m depth	<20 m depth	<40 m depth	Total (20 m depth)	Total (40 m depth)
0 (No)	115	37	74	152	189	189
	60.85	19.58	39.15	80.42	100	100
	50.44	37	47.44	53.52	49.22	49.22
1 (Yes)	113	63	82	132	195	195
	57.95	32.31	42.05	67.69	100	100
	49.56	63	52.56	46.48	50.78	50.78
Total	228	100	156	284	384	384
	59.38	26.04	40.63	73.96	100	100
	100	100	100	100	100	100

Source: Author's calculation using Stata 17

Table 4–6. Key components of experimental settings

	Component description
Definition of the participants.	Out of the 102 rural dwellers who were invited to participate in the experimental games, 62 individuals showed up during the trials. The participants belonged to 10 communities mostly depending on groundwater, which are part of four municipalities characterized by being exposed to frequent droughts.
Treatment design and application	▪ The participants were divided into two groups: No hydrogeological information and no communication allowed. Hydrogeological information provided and communication allowed. ▪ Two treatment information groups were organized to differentiate water allocation decision-making: Allocation when the amount of water in the aquifer was declining and allocation when the remaining *time* before aquifer exhaustion was announced.
Rounds	A total of 668 series of experimental sessions were run with the 62 participants. The rounds corresponded to the years or time periods in which players, distributed their allocated/extracted water units.
Payment method	*For each unit allocated to activity $W_{(p)}(t)$, the subject earned an individual payoff of 10 $COP. The payoff for allocating one unit to activity $S_{(p)}(t)$was 5 $COP and had the nature of a collective good. Allocation to $W_{(f)}(t)$ had the nature of a private benefit to be exploited in the future, which yields an individual payoff of 4 $COP per unit of water. The aggregate payoff from all activities determined a subject's payoff for the game. The participants had another source of earnings, which corresponds to the sum of the contributions made by every participant $\sum S_{(p)}(t)$. They received a share μ of this total amount. In the experiment, the average earning was almost five times the minimum hourly wage in Colombia, i.e., $19,000 in cash was paid to each participant.* *The payoff was assigned to an individual appropriator for investing in the collective resource depended on the aggregated group investment in the CPR and on the appropriator's investment as a percentage of the aggregated contributions (Ostrom et al., 1994). The group's return on investment in the common pool was calculated by the production function $\mu\sum S_{(p)}(t)$. The payoff function (π_i) had different*

(*continued on next page*)

(*continued*)

	Component description
	components, as follows: $\pi_i = \theta - \alpha$. θ *represented the endowment (cap) of water;* ρ *corresponded to the discount rate that each individual i made his/her decision to preserve water for the future;* μ *reflected the collective gain perceived by all participants upon the contributions of j individuals. This marginal payoff for contributing to the collective good was equal to 0.2, indicating that no matter how much the participants contributed to the collective consumption, each of them received a 0.2 fraction of the aggregated contribution of all participants. The contribution in water units was converted into the monetary payoff, where* α *represented the present marginal water consumption for individuals.* *Since a hyperbolic discount was considered,* ρ *corresponded to the discount rate that each individual i assigned to his/her decision to preserve water for the future. In the hyperbolic discount factor,* $b/(1+\rho)^t$ *(Phelps and Pollak, 1968)*[a]*. If* $b < 1$ *this function discounts immediate delays more dramatically than an exponential one, because the current utility has a weight of one, while the utility one period from now has a weight* $b/(1+\rho)$.
Behavior of the participants and their allocation to the collective good	The good under consideration refers to water from the underground which entailed a collective access character; participants were asked to decide or choose how many units each one was willing to extract. Units referred to cubic meters of water.

[a]Cited in (Camerer, 1998)
Source: based on (Cartwright, 2019; Cassar and Friedman, 2004; Smith, 1992)

A note on the qualitative information gathered during quantity treatment group sessions

In the setting of the field experiments, during the interviews the farmers were asked how to reduce water extraction from the ground. In response, different elements came to the scene, as shown in in Table 4–7.

Table 4–7. Reactions of farmers when asked how to adapt to water table declinations

Reactions observed in the field	Source of narratives
o Farmers usually confront their habits	→ Replies observed in La Guajira and Sucre during experimental sessions.
o Calculating the effect on expected profits	→ Replies on available water reductions observed in Sucre and on exacerbated droughts observed in La Guajira.
o Thinking of alternative water sources	→ Narratives after field experiments in Magdalena, Sucre and La Guajira.
o Inquiring on water reduction duration	→ During all field experimental sessions, the players asked whether the sacrifice in terms of water extraction reduction would last all rounds, or less or more than the 12 or 13 rounds.
o Inquiring if the other farmers are about to be involved in the same water extraction reductions.	→ Narratives observed in La Guajira and Magdalena after field experiment discussions.
o Making some efforts to calculate volumetric extractions.	→ Actions observed during experimental sessions in Sucre and La Guajira (Fonseca and La Reserva Communities), while farmers used calculators for this counting.
o The custom of favoring water outflow over inflow.	→ Concluded while observing respondents in La Guajira (Community La Plazoleta) and Sucre (Community Las Llanadas).
o Despite water table declination, farmers usually think of aquifers as limitless resources.	→ Narratives and expressions observed in different communities in Fonseca (La Guajira) and Guamal (Magdalena).
o Water-well builders usually suggest that the more water is extracted, the more productive wells become.	→ Perceptions observed in Riohacha (La Guajira) and Guamal (Magdalena) during interviews with well builders.
o Building community boreholes.	→ During discussions held after field experiments in different communities in Fonseca and Riohacha (La Guajira) and in Guamal (Magdalena), in communities Los Andes and San José de Paraco.
o Shifting or improving extraction technology	→ Feedback reports from participants in interviews and field experiments in Sucre, La Guajira and Magdalena.
o Other behavioral issues worth further investigation	→ Uncertainty, lack of knowledge on socio-hydrogeologic issues, routines, belief that underground water stocks influence the adoption of adaptive behavior to scarcity.

One of the first reactions observed in the quest for adaptation to water scarcity among farmers was appealing to confront their habits. This comes from replies observed in La Guajira and Sucre, such as: "I must irrigate my crops in the present"; "we have some customers to supply with our vegetables, tubers and all the products of our crops, so we do not know how to change irrigation patterns"; "we have become accustomed to collecting water from underground, and there are few options to collect water from distant places". After confronting habits, farmers usually think about the effects of water extraction changes on their expected profits. Replies on reductions in available water in Sucre focused on "how should we adapt to declining water tables if our farms sustain our local economies?" Similarly, in La Guajira there is high expectation of the influence of declining water tables on agricultural profits. This is especially relevant for communities dependent on external funding for irrigation projects. If extraction should be reduced, farmers inquire if the other farmers are about to follow this implementation as well. Narratives recorded in La Guajira and Magdalena revealed that the participants inquired if other water users in the vicinity were being similarly asked to engage in extraction reductions and water saving.

When extraction reduction becomes part of a set of feasible strategies intended to adapt to water scarcity, farmers start making efforts to calculate volumetric extractions. When farmers relying on aquifer systems are asked about extraction volumes, they only have partial knowledge on this topic. Some mental calculations are done before reporting this figure. As a researcher, one usually finds some cues about using water pump horsepower or water flow capacity to have a slight idea of this volume. Otherwise, the size of the container where water is stored is similarly used to calculate volumetric extractions. In some cases, in La Guajira and Sucre, farmers grabbed the calculator to do some math on how much they might reduce water application to the crops to adapt to declinations. However, water table declination does not necessarily activate mental adaptation. Despite water table declination, farmers usually think of aquifers as limitless resources. So why measure something that will not be exhausted during life on earth? (*Unlimited stock belief*). The tendency to keep extracting as an adaptive strategy (i.e., favoring outflows) shows how it prevails over the possibility to favor inflows. Water users mostly focus on outflows and, therefore, have little interest in increasing inflows aimed at improving or replenishing aquifer systems (*outflow routine effect*). Few respondents in La Guajira (Community La Plazoleta) and Sucre (Community Las Llanadas) replied to the need to improve the recharge capacity of aquifers, i.e., increasing inflows instead of simply extracting. In cases in which building private boreholes is not feasible, farmers appeal to collective action to access groundwater.

Building community boreholes is a collective strategy intended to cope with the costs of water-well construction and water extraction. For farmers and households with limited access to groundwater or limited financial means to build deep private boreholes, the construction of community water-wells has been implemented to satisfy water needs. This was observed in different communities in the municipalities of Fonseca and Riohacha (La Guajira) and in the communities of Los Andes and San José de Paraco of the municipality of Guamal (Magdalena). When the available private or collective water access technology does not allow affordable extraction, improved extraction technology has been proposed as an adaptation strategy. In Sucre, La Guajira and Magdalena, some farmer-level initiatives to deal with reduced well productivity and declining water tables were frequent. Some farmers reported shifting to powerful pumps, changing hoses and pipes in the irrigation network, building tall water tanks, giving maintenance service to boreholes and other measures to apply more water to crops. Nevertheless, these solutions might not last long if individual approaches continue.

References

Apraku, B., Idinoba, M., Amisah, S., 2008. Water scarcity under a changing climate in ghana: options for livelihoods adaptation. Development *51*, 415–417. https://doi.org/10.1057/dev.2008.46.

Asprilla-Echeverría, 2022. Drivers of adaptation to water scarcity: extraction caps in field experiments. J. Groundw. Sustain. Dev. Vol. 19 https://doi.org/10.1016/j.gsd.2022.100827.

Camerer, C., 1998. Bounded rationality in individual decision making. Exp. Econ. https://doi.org/10.1007/bf01669302.

Cardenas, J.C., Rodriguez, L.A., Johnson, N., 2011. Collective action for watershed management: Field experiments in Colombia and Kenya. Environ. Dev. Econ. https://doi.org/10.1017/S1355770×10000392.

Cárdenas, J.C., 2009. Dilemas de lo colectivo: instituciones, pobreza y cooperación en el manejo local de los recursos de uso común. Ediciones Uniandes. Universidad de los Andes.

Cassar, A., Friedman, D., 2004. Economics lab: an intensive course in experimental economics. Vasa. https://doi.org/10.1017/CBO9781107415324.004.

Condon, A.; Richards, R.; Rebetzke, G. & Farquhar, G. (2004). Breeding for high water-use efficiency. 10.1093/jxb/erh277.

Damania, R., Desbureaux, S., Hyland, M., Islam, A., Moore, S., Rodella, A-S., Russ, J., & Zaver, E. (2013). UNCHARTED WATERS: The New Economics of Water Scarcity and Variability. 7 International Bank for Reconstruction and Development / The World Bank. doi:10.1596/978-1- 4648-1179-1.

Fischbacher, U., Gächter, S., Fehr, E., 2001. Are farmers conditionally cooperative? Evidence from a public goods experiment. Econ. Lett. https://doi.org/10.1016/S0165-1765(01)00394-9.

Gächter, S., 2007. Conditional cooperation: behavioral regularities from the lab and the field and their policy implications about the Centre or contact. Econ. Psychol. A Promis. N. Cross-Discip. Field, April 2006(2006–3 19–50.

Grafton, R., Williams, J., Perry, C., Molle, F., Ringler, C., Steduto, P., Udall, B., Wheeler, S., Wang, Y., Garrick, D., Allen, R., 2018. The paradox of irrigation efficiency. Science *361* (6404). https://doi.org/10.1126/science.aat9314.

Griffin, R., 2006. Water Resources Economics: The Analysis of scarcity, policies and projects. Massachussetts Institute of Technology, Cambridge.

Harlan, S.L., Yabiku, S.T., Larsen, L., Brazel, A.J., 2009. Household water consumption in an arid city: affluence, affordance, and attitudes. Soc. Nat. Resour. https://doi.org/10.1080/08941920802064679.

Harrison, G.W., List, J.A., 2004. Field experiments. J. Econ. Lit. https://doi.org/10.1257/0022051043004577.

Hoekstra, A.Y., 2013. The water footprint of modern consumer society. Water Footpr. Mod. Consum. Soc. https://doi.org/10.4324/9780203126585.

Keser, C., Van Winden, F., 2000. Conditional cooperation and voluntary contributions to public goods. Scand. J. Econ. *102* (1), 23–39. https://doi.org/10.1111/1467-9442.00182.

Laibson, D., 1998. Life-cycle consumption and hyperbolic discount functions. Eur. Econ. Rev. https://doi.org/10.1016/S0014-2921(97)00132-3.

Ledyard, J., 1995. In: J. H. K., Roth, A.E. (Eds.), Public Goods: A Survey of Experimental Researc. Princeton University Press, Princeton Nw Jersey. https://doi.org/10.1515/9780691213255-004.

Margat, J., van der Gun, J., 2013. Groundwater around the world: A Geographical Synopsis. International Groundwater Resources Assessment Center (IGRAC). United Nations Educational, Scientific and Cultural Organization (UNESCO), International Hydrogeological Programme.

Meadows, D., 2008. In: Wright, D. (Ed.), Thinking in Systems A primer. Chelsea Green Publisher, Vermont. Retrieved from. ⟨https://www.chelseagreen.com/product/thinking-in-systems/⟩.

Mehta, L., 2007. Whose scarcity? Whose property? The case of water in western India. Land Use Policy 24, 654–663. https://doi.org/10.1016/j.landusepol.2006.05.009.

Mekonnen, M., Hoekstra, A., 2016. Four billion farmers facing severe water scarcity. Sustainability *2*. https://doi.org/10.1126/sciadv.1500323.

Metha, L., 2007. Whose scarcity? Whose property? The case of water in western India. Land Use Policy *24*, 654–663. https://doi.org/10.1016/j.landusepol.2006.05.009.

Ostrom, E., Gardner, R., Walker, J., 1994. Rules games and common pool resource problems. Rules, Games, Common-Pool. Resour. 3–21.

Pahl-Wostl, C., Knieper, C., 2014. The capacity of water governance to deal with the climate change adaptation challenge: using fuzzy set Qualitative Comparative Analysis to distinguish between polycentric, fragmented and centralized regimes. Glob. Environ. Change *29*, 139–154. https://doi.org/10.1016/j.gloenvcha.2014.09.003.

Singh, Ch, Osbarh, H., Dorward, P., 2018. The implications of rural perceptions of water scarcity on differential adaptation behaviour in Rajasthan, India. Reg. Environ. Change *18*. https://doi.org/10.1007/s10113-018-1358-y.

Spinti, J.E., Hilaire St., R., VanLeeuwen, D., 2004. Balancing Landscape Preferences and Water Conservation in a Desert Community. HortTechnology.

UNWATER, 2023. The United Nations World Water Development Report 2023: Partnerships and Cooperation for Water. UNESCO, Paris.

Van der Gun Jac 2022.https://doi.org/10.21083/978-1-77470-020-4.

Velez, M.A., Stranlund, J.K., Murphy, J.J., 2009. What motivates common pool resource users? Experimental evidence from the field. J. Econ. Behav. Organ. https://doi.org/10.1016/j.jebo.2008.02.008.

Wolfe, S., Brooks, D., 2003. Water scarcity: an alternative view and its implications for policy and capacity building. Nat. Resour. Forum *27*, 99–107.

World Bank, 2010. Deep wells and prudence: towards pragmatic action for addressing groundwater overexploitation in India. Int. Bank Reconstr. Dev. / World Bank 120.

Yuan, X., Wang, Y., Ji, P., Wu, P., Sheffield, J., Otkin, J., 2023. A global transition to flash droughts under climate change. Science 380, 187–191. https://doi.org/10.1126/science.abn6301.