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What facilitates adaptation? An analysis of community-based adaptation to environmental change in the Andes

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Abstract: This study analyses the environmental, socio-economic and institutional factors that influence community-based adaptation strategies in 16 municipalities in the rural Andes of Colombia. The study focuses specifically on the factors that influence whether communities decide to take measures to manage their water and micro-watersheds in response to water scarcity caused by climate variability and land-use changes. The research uses quantitative and qualitative methods incorporating data from surveys to 104 water user associations, precipitation and land-use data, municipal socio-economic information, and semi-structured interviews with key informants. The results reveal 1) the links between environmental change and the type of adaptation that communities implement, and 2) how, in face of water scarcity changes, external funding facilitates adaptation. The findings of this study contributes to the common-pool resource and adaptation literatures by highlighting the important role that external actors may have in shaping collective action to adapt to environmental change.

Keywords: Adaptive capacity, autonomous adaptation, climate-change, common pool resources, commons, conservation, deforestation, disturbance, governance, resilience, resource management, socio-ecological systems, sustainable development, vulnerability

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1. Introduction

Water scarcity is a critical challenge to socio-ecological systems. In the Andes, global climate model predictions of changes in total rainfall remain highly uncertain. In general, however, climate models in the Andes predict an increase in rainfall variability and, as a consequence, an increase in the frequency and duration of periods with water scarcity (Vera et al. 2006; Boulanger et al. 2007; Buytaert et al. 2009). In anticipation of these changes, governments and NGOs are working with communities, local management systems, and public utilities to promote adaptation strategies. However, in order for adaptation policies and programs to be effective, we need to understand what communities are currently doing to respond to water scarcity changes; learning from these experiences will help us support further behaviours that facilitate adaptation. Particularly, we need to better understand the key factors that trigger adaptation (Engle 2011; Lemos et al. 2013).

This paper examines the strategies that Andean communities in Colombia are using to adapt to changes in water availability. In this context, adaptation strategies are understood as conscious processes or actions in a system in order to respond to a current or predicted environmental, socio-economic or institutional disturbances (Smit and Wandel 2006; Nelson et al. 2007; Murtinho and Hayes 2012). Field research studies that empirically assess adaptation are critical for building a more comprehensive theory of adaptation, so that policy initiatives can be tailored to fit the particular needs of communities and contexts in which adaptation processes occur (Wood et al. 2014). Though important, this kind of field research is met with a number of challenges. First, researchers must empirically assess adaptation to determine possible causal links between disturbances and adaptations (Smit and Wandel 2006; Murtinho and Hayes 2012; Noble et al. 2014). In one example of this challenge, the fifth assessment report of the Intergovernmental Panel on Climate Change (IPCC) highlights that one of the barriers in measuring adaptation has been the difficulty of distinguishing between regular investment activities to improve natural resource management (i.e. normal development) and actual responses to climate change (Noble et al. 2014). The complex motives behind human behaviour and the multitude of changes an individual or community may be facing complicate this challenge (Eakin 2005; Eakin and Wehbe 2009). In addition, rather than simply assuming that observed environmental changes are the driving motivations for policy change, to understand adaption it is necessary to explicitly define motivations from the perspective of the decision-makers.

As a second challenge, we need to understand how collective behaviour influences adaptation. Much of the adaptation research, especially quantitative studies, has focused on individual behaviours to adapt to environmental change.

For example, studies highlight key factors such as rural infrastructure, education systems, agricultural extension, micro-credit services, social capital, assets, access to weather information, and climate change beliefs that facilitate adaptation among farmers (Below et al. 2012; Wheeler et al. 2013; Wood et al. 2014). However, Adger (2003) argues that in addition to research on how individuals implement adaptation strategies, we need to understand more about how individuals act collectively to adapt. While the adaptation literature has focused on individual decision-making to adapt, researchers from the common-pool resources field have studied for decades how communities make decisions to collectively manage their shared natural resources (Ostrom 1990; Agrawal 2001). These studies highlight certain characteristics, such as socio-economic and organizational factors, that facilitate collective action to manage local resource systems, including water systems (Meinzen-Dick et al. 2002; Araral 2009; Villamayor-Tomas 2014).

Much of this research on collective approaches to adaptation, however, has focused on resource management in communities that have remained relatively buffered from exogenous environmental, demographic, political and market changes (Cox 2014). Although these studies analyse how communities manage their resources usually under constant internal changes (i.e. fishing, harvesting or rainfall seasons), exogenous changes can present new challenges for communities, especially if these changes are beyond normal variability (Marschke and Berkes 2006). While some researchers examine how resource users collectively mobilize to address external change (Smit and Wandel 2006; Hayes 2008; Villamayor-Tomas 2014), we have yet to identify key factors that facilitate adaptation to uncertain changing conditions such as climate variability and land-use changes.

This article aims to contribute to the literature on adaptation and common-pool resources by (1) specifically contrasting the environmental and socioeconomic changes that communities are facing with the type of responses that communities implement, and (2) understanding the key factors that trigger community-based adaptation. Because many rural communities must decide by themselves if and how they will protect their watersheds and distribute their water under uncertain and changing conditions, this research is especially important in many regions of the less developed world. In the Andean countries, for example, autonomous Water User Associations (WUAs) distribute water to almost 25% of the population in the region (AVINA 2011).

This study employs quantitative and qualitative methods to understand the factors that facilitate adaptation to water scarcity changes among WUAs. While framing the paper in the climate change literature, this paper focuses on water variability, specifically on adaptation to resource scarcity (Forsyth and Evans 2013). As this study shows, in rural areas of the Fúquene watershed, located in the eastern Andes of Colombia, WUAs are adapting to increasing water scarcity due to land cover changes and rainfall variability (Murtinho et al. 2013a). Similar to other watersheds in Latin America (De Bievre et al. 2012; Madrigal-Ballestero and Naranjo 2015; UNDP 2015), WUAs in Fúquene are implementing adaptation strategies such as purchasing land to conduct ecosystem restoration in order to improve water regulation, building additional water tanks to increase water storage, and reducing water demand by increasing prices and installing metering devices in each household (Murtinho et al. 2013b). The following section of this article, then presents the theoretical background on the factors that facilitate adaptation. This is followed by an overview of the study site and a description of the methods used in the analysis. Finally, using findings from 104 WUAs in Fúquene, the results and discussion sections offers an analysis of the factors that facilitates (or impede) the implementation of adaptation strategies.

2. Theoretical background

Given that community-based adaptation is rooted in the ability of households to cooperate, specifically in the case of common-pool resources such as water, this study draws from the socio-ecological system (SES) framework (McGinnis and Ostrom 2014) to explore the factors that facilitate communal decision-making to adapt (Madrigal-Ballestero and Naranjo 2015). The SES framework provides a useful way of identifying potential variables, and can be organized in five broad categories including (1) social, economic and political settings; (2) resource systems and units; (3) governance systems; (4) actors; and (5) interactions and outcomes. Following previous studies, not all categories and subcategories of the SES framework are included in the analysis (some factors do not have appreciable variation among cases or they are not relevant to the research question) (Basurto and Ostrom 2009; Madrigal-Ballestero and Naranjo 2015).

The first group of key drivers of adaptation is the social, economic and political context. Studies show that a region's socio-economic characteristics (e.g. infrastructure investment, poverty) can provide opportunities or challenges for communities' adaptation (Eakin 2005). Also, demographic changes can lead to increasing demand for natural resources, generating scarcity that could motivate communities' responses (Coulthard 2008).

The second category, the resource system and units can influence communities' decisions by creating the disturbances that communities will try to respond (Burton et al. 1993; Eakin 2005). Researchers argue that the frequency and intensity of environmental disturbances (major shocks or continuous slow pressures) in part determine the likelihood of adaptation (Marschke and Berkes 2006).

Third, researchers argue that adaptation can also be triggered by governance system changes, such as alteration of resource access rules (Janssen et al. 2007), and community property rights (e.g. right to manage their resources) that could influence self-organization (Ostrom 1999; Berkes and Turner 2006).

In addition, the attributes of the actors using the resource have been shown to be important facilitating adaptation. For instance, studies show that higher household income allows communities to mobilize internal or external financial resources to have access to appropriate infrastructure and technology so that communities can assume the costs of the adaptation strategies (Pretty and Ward 2001; Ivey et al. 2004; Grothmann and Patt 2005). Besides income, size is an indirect community characteristic that influences adaptation. Although bigger associations might have more financial resources to invest in adaptation strategies (Poteete and Ostrom 2004), smaller communities can cooperate and manage communal natural resources more easily, including water systems (Agrawal 2001; Meinzen-Dick et al. 2002; Poteete and Ostrom 2004; Fujiie et al. 2005). In addition, when associations have had a long time of organizational experience that has offered them more opportunities to learn, either from previous experiences (trial and error responses) or from interaction with others like neighbours, NGOs and governmental agencies, adaptation is also more likely to occur (Carpenter et al. 2001; Berkes and Turner 2006; Lebel et al. 2006). Finally, the education level of community members has also been shown as an important factor to trigger cooperation (Meinzen-Dick et al. 2002).

Finally, the interactions among resource users and external organizations such as NGOs and governments are important drivers for adaptation. Studies show that social networks among communities and their political connections with the government are key factors influencing the likelihood to request and obtain funding that could support community-based adaptation (Pretty and Ward 2001; Ivey et al. 2004; Adger et al. 2005).

3. Study site

The study examines community water management in the "Fúquene watershed," a watershed of the Ubaté and Suárez Rivers located in the northern part of the eastern mountain range of the Andes, approximately 100 km north of Bogotá (see Figure 1). Because it is largely representative of political, socio-economic and ecological processes occurring throughout the Colombian Andes with respect to local water management, Fúquene provides an ideal location to study water management adaptation. Similar to many other Andean regions, water from this watershed remains vital to all households in the area (CAR 2006); when the water supply is scarce or has deteriorated, only a few if any alternative water consumption sources are available.

Fúquene watershed covers 1980 km^2. The area exhibits a bi-modal rainfall regime, with 6 months of a relatively drier season or "summer" (32% of total annual rainfall). The average rainfall in the watershed is 905 mm/year, however, rainfall is unequally distributed; the northern part of the watershed has higher average rainfall in both wet and dry season (680 mm and 289 mm, respectively) than the southern region (405 mm and 254 mm) (Murtinho et al. 2013a). Similar to most Andean regions in Colombia, the watershed's elevation (between 2400 and 3750 m) is insufficient to harbour glaciers or snowpack as a dry season water source. In 2005, only 17% of the Fúquene territory was covered by native and partially intervened ecosystems (Murtinho et al. 2013a), including strategic water regulators such as páramos (tropical alpine grass and wetlands) and forests (Buytaert et al. 2006; Harden 2006).

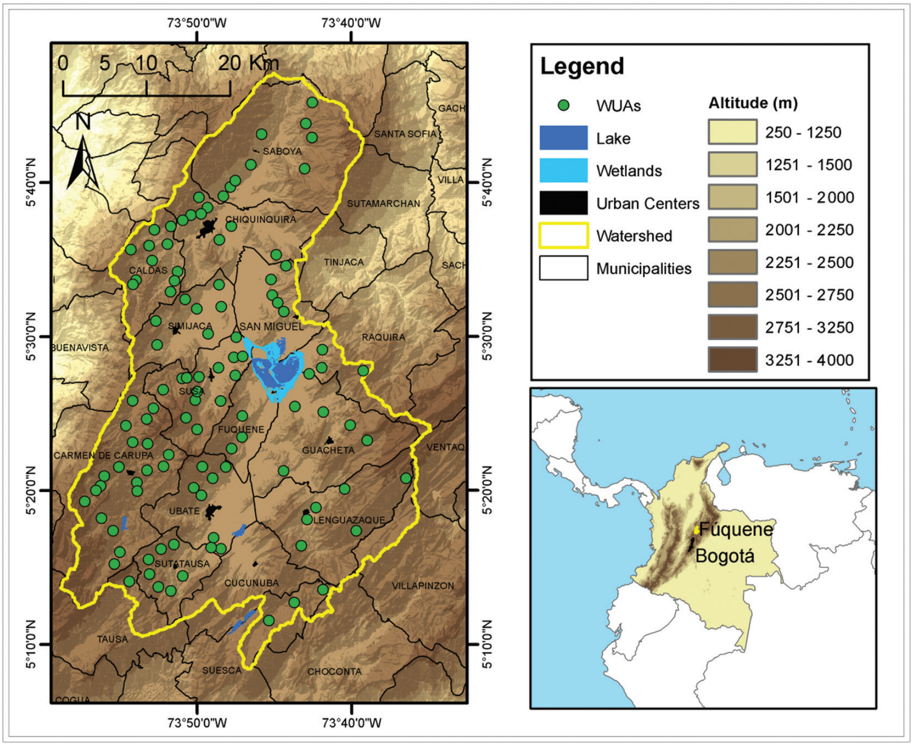

Figure 1: Fúquene Watershed location.

Within the watershed, approximately 55% of the inhabitants (115,000) live in rural villages (DANE 2005). Similar to other Andean regions in Colombia, poverty levels range from 25% to 50% in the rural population (DANE 2005). As in other regions of the Colombian Andes, land is privately owned. The majority of the people inhabit the upper areas of the watershed, where land is least productive and devoid of irrigation systems. This study focuses on the upper areas of the watershed, where local families work small parcels of land that are usually <2 hectares (Flórez 2005; Murtinho et al. 2013a).

The Regional Autonomous Corporation (CAR) is the agency in charge of implementing national water and environmental policies for the Fúquene watershed. Some of the CAR's responsibilities include provision of water use permits and regulation (including monitoring and sanctioning) to prevent deforestation and contamination activities. Similar to other regions in Latin America, water distribution is traditionally administered by municipal public water utilities. In Fúquene, the watershed is divided into 16 municipalities or counties. Due to lack of technical and financial resources, however, public utilities in these municipalities generally provide water only to urban centers and to the urban periphery.

In rural areas, autonomous WUAs frequently manage village water systems. In the absence of external governmental intervention, WUAs have often emerged to solve conflicts of water distribution due to increasing demand and water shortages in the dry seasons (Peña et al. 2007). In 2005, water associations provided water to 41% of Colombia's rural population (approximately 4.5 million people) (Colmenares and Mira 2007). One hundred and twenty eight WUAs exist in Fúquene. The purpose of these associations is to distribute water for household consumption, although in most cases without appropriate water purification systems. WUAs' operational activities, and in some cases infrastructure investments, are funded by households' water consumption fees, which are imposed and collected by the WUAs on the basis of communal decisions at the annual assembly meetings. In addition, local governments support WUAs' investments. As in many other areas of Colombia, local government investments are distributed based on a clientelist basis inside each municipality (where political connections are needed to obtain funds, and usually in exchange for votes) (Flórez 2005). Beyond financial resources for infrastructure investment (mostly from municipal funds), paltry support exists for WUAs in Fúquene. Most of the associations have not received water management training (or informal education) from the government, and none of them have received training from non-governmental organizations (NGOs) (Murtinho et al. 2013b).

Previous research in Fúquene (Murtinho et al. 2013a) found that during the wet season most WUAs (91%) have enough available water to distribute it every day to each household. However, during the dry season only 59% of WUAs can distribute water daily. At the time of the study, 51% of WUA leaders perceived that there were medium, high or very high water scarcity problems in the dry season. According to the study, WUAs identified land cover and rainfall changes as the two main causes of higher water scarcity. WUA leaders' perceptions are corroborated with analysis of land cover maps covering the time period between 1987 and 2005. However, analysis of rainfall data in Fúquene during the last 44 years shows that there are no statistically significant changes in rainfall trends, either in its distribution along the year, or in the frequency of dry events (see Figure 2). The 2013 study also shows that WUAs in municipalities with higher rainfall differences between the wet and dry season perceive higher water scarcity. Although El Niño events have a similar impact in the region (reduction of precipitation), WUAs with high variability between seasons, are more likely to perceive crisis events (understood as a severe reduction of water availability). Finally, that study found no evidence that demographic changes (that could increase water demand) and institutional changes (policies that could change water distribution rights) are causing water scarcity changes in Fúquene.

4. Data sources and methods

This study's mixed methods approach combines statistical and qualitative analysis to further interpret and validate the statistical results. The principal source of data for this analysis is a questionnaire administered to WUA leaders in the Fúquene

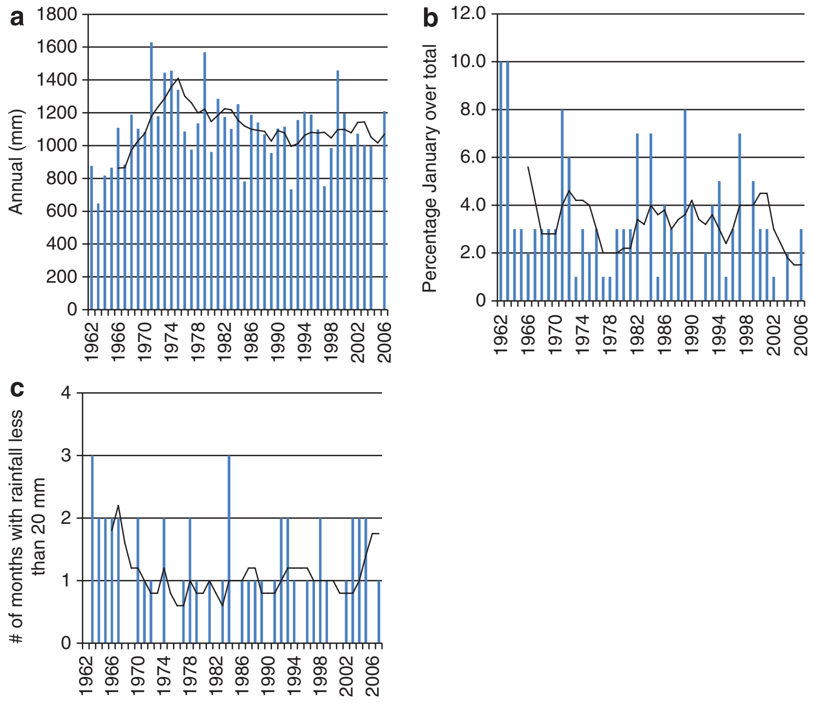

Figure 2: Precipitation trends in northern station: (a) annual rainfall (mm), (b) January fraction (%) and (c) dry spells (# of months with rainfall <20 mm). (Black line is 5-year moving average).

watershed in 2008. I interviewed representatives from 120 of the 128 WUAs located in the region. After excluding 16 WUAs that were identified as exceptional or had missing information, the final study sample includes 104 WUAs. Those structured interviews included questions focusing on the characteristics of their associations, their perceptions of water scarcity, and their implemented adaptation strategies. To more fully understand the socio-ecological context, including the water governance processes in the region, I also interviewed 35 key informants (including government officials and NGO personnel) in the Fúquene watershed. Government data based on public investment and demographic data provided additional socio-economic information. Finally, I gathered salient environmental information from land cover-land use maps from 1987 and 2005 (scale 1:100,000) (IAvH 2007) and monthly rainfall data between 1962 and 2006 for 13 stations inside the watershed.

4.1. Dependent variable

Initiative on the part of local WUA leaders to adapt to water scarcity in the Fúquene region is the dependent variable in this study. To identify adaptations initiated by WUAs in Fúquene, WUA leaders were asked about the activities or

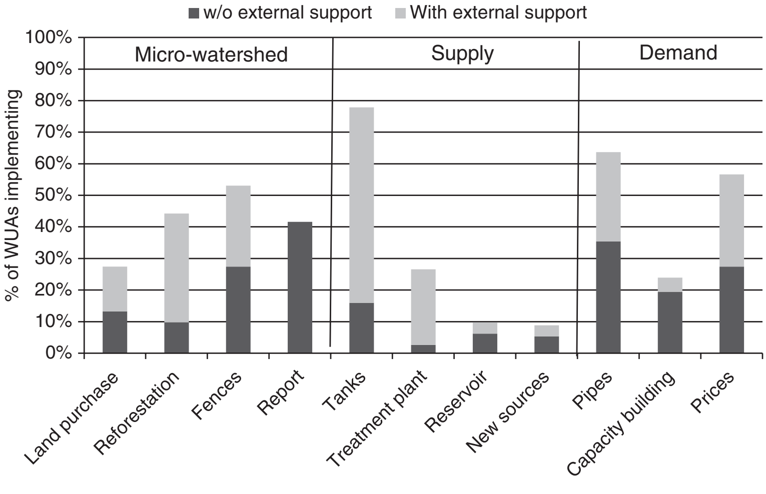

Figure 3: Percentage of WUAs implementing adaptation strategies.

investments they had implemented to respond to perceived actual or potential water availability changes. In Fúquene, activity or investment was considered to be an "adaptation strategy" if it was (1) a conscious investment specifically to solve water scarcity problems, and (2) initiated by WUA leaders who then participated in the implementation process (even if financial sources came from the government). Because there was no WUA initiative or involvement in implementation of unsolicited help, donations or gifts were not categorized as adaptation strategies.

Similar to previous research (Kundzewicz et al. 2007; Noble et al. 2014; Madrigal-Ballestero and Naranjo 2015), the adaptation strategies that WUAs are implementing in Fúquene are classified in three categories: i) micro-watershed management, ii) supply water management, and iii) demand water management. Figure 3 also distinguishes strategies financed with WUAs' internal resources and those that received external financial support from local governments (see Murtinho 2013 for a description of these adaptation strategies).

An aggregated adaptation strategies index was used to compare the 11 adaptation strategies across communities (Murtinho et al. 2013b). Previous research on adaptation has used expert assigned weights according to its potential ability to reduce water scarcity problems to aggregate strategies (Below et al. 2012). In the absence of previous studies in the region on the impacts of each of these 11 strategies on water availability,[1] and due to complimentarity of

[1] Although there are studies that assess the impacts of land use changes on water availability in other regions (see Celleri and Feyen 2009 for a review), these studies are context dependent, and it would be hard to extrapolate these results to Fúquene.

selected adaptation strategies, this study followed work by Fujiie et al. (2005) on collective action in irrigation systems and created an index using principal component analysis (PCA). Given the propensity of WUA leaders to initiate a number of WUA strategies, many of which were complementary, a simple sum of the strategies was not appropriate for the aggregation.

According to WUA leaders (Murtinho et al. 2013b), no single strategy (or group of strategies) was sufficient to solve water scarcity problems. Acting on the belief that associations that implemented more strategies were more likely to solve or reduce potential water scarcity problems, WUAs tended to implement multiple strategies. Furthermore, many strategies were complementary; for example, when an association purchased land for conservation, they also tended to develop reforestation projects. To build the index used for this study, the 11 strategies for each WUA were weighted using PCA. The adaptation strategy variables were normalized to have a mean equal to zero and standard deviation equal to one, in order to use the co-variance matrix to extract all the principal components where the associated eigenvalue is >1. The index is calculated as the sum of the 11 normalized variables weighted by the coefficients of the first component. Following previous studies, the first component is more appropriate and easier to interpret as the weights to aggregate the variables (Fujiie et al. 2005; Vyas and Kumaranayake 2006). As expected, all weights have positive value (see table 1 in the Appendix). The calculated index ranges from a maximum of 2.8 points and a minimum of –1.8, with a mean of 0. The more adaptation strategies implemented by the WUA, the higher the index. Finally, in order to compare different types of strategies, in addition to the overall adaptation index, three additional indices were built to aggregate adaptation strategies and distinguish three categories of water management (micro-watershed, supply and demand strategies) (see table 1 in the Appendix).

4.2. Independent variables

Variable selection was based on the SES framework (McGinnis and Ostrom 2014; Madrigal-Ballestero and Naranjo 2015), studies on climate change adaptation literature (Ivey et al. 2004; Eakin 2005; Grothmann and Patt 2005; Berkes and Turner 2006), the results of semi-structured interviews to key informants, and results from previous econometric studies of the factors that influence cooperation in irrigation case studies (Meinzen-Dick et al. 2002; Fujiie 2005; Araral 2009). To assess the importance of these variables on the decisions to adapt, I used Stata 13 to estimate ordinary least squares regression models. To do this, I revised each model so that it complies with OLS regression assumptions (i.e. heteroscedasticity, endogeneity, multicollinearity). The hypothesized relations between the predictor variables and the adaptation index are summarized in Table 1. A plus or minus sign is assigned to indicate the anticipated direction of the relation between the predictors and adaptation. Following the SES framework, each group of variables is described below.

Table 1: Summary independent variables.

Variables	Description	Expected	Mean	S.D.	Min.	Max.
Socio-economic settings						
Mun. water invest	5-Year avg $US/hab	+	30.3	11.6	13.1	55.5
Rural poverty	% of households	–	36.4	10.3	24.0	62.3
Rural pop density	Pop/Km^2	+	51.9	28.0	23.3	141.5
Resource systems and units						
Summer rainfall	% of total annual rain	–	16.2	0.9	15.1	18.6
Land cover change	% of change 1987–2005	–	–16.2	24.1	–54.9	24.3
Governance system						
Legal registry	1=yes	+	0.6	0.4	0.0	1.0
Actors						
WUA size	# users	±	126.1	121.8	12.0	575
WUA income	US$/month/user	+	1.1	1.1	0.0	6.3
WUA experience	Years	+	16.9	9.5	0.1	43
Leader education	Years	+	8.3	4.8	1.0	16
Leader resides inside community	1=inside	±	0.8	0.3	0.0	1.0
Interactions						
Request external support	% of total strategies	+	33.4	19.4	0.0	70
WUA political connections	%	+	60.9	36.3	0.0	100

4.3. Socioeconomic and political settings

The first group of analysed variables includes three socio-economic variables: First, it is expected that WUAs located in municipalities that have higher municipal investment in rural water projects (measured as a 5-year average per habitant) will have more chance of receiving support to invest in adaptation strategies. Second, because WUAs located in municipalities with high poverty levels could have more problems collecting users' fees to implement adaptation strategies, rural poverty (% of households with unsatisfied needs) could have negative effects on adaptation. Lastly, rural population density in 2005 is selected to understand demographic trends that could affect water demand.[2] It is expected that WUAs in municipalities with higher population density will implement strategies to deal with increasing water demand.

4.4. Resource system and units

Two variables are included to assess the predictability of water supply. First, as discussed earlier, because there are no increasing or decreasing trends in Fúquene's rainfall, long-term trend variables were not included in the analysis. However, as previously explained, WUAs in municipalities with higher rainfall differences

[2] In previous analysis there is no evidence that rural population density or population change is causing water scarcity (Murtinho et al. 2013a). However, because it could be an important proxy to measure water demand, population density was included in the analysis. Because of missing information from one municipality, population change was not included.

between seasons (lower proportion of summer rainfall) perceive higher water scarcity and crisis events. It is expected that WUAs located in regions perceived as more exposed to El Niño events will implement more adaptation strategies. Second, land cover change is measured between 1987 and 2005; it includes native and partially intervened ecosystems. It is expected that loss of ecosystems such as forests and páramos, critical for water regulation, will motivate WUAs to take actions to protect their micro-watersheds.

4.5. Governance systems

As explained earlier, all WUAs face similar environmental regulations and policies from the regional environmental authority, so in order to assess the property-rights system variations among WUAs, I included a variable that measures if the WUA is legally registered as a community-based organization. All WUAs are autonomous and can create and modify their own water management rules. However, registered WUAs are legally recognized by the government to create and modify these rules. Being legally registered gives WUAs access to funding and allows them to make contracts with the government. The process of legally registering involves relatively high transaction costs, and some WUA leaders do not have the knowledge or financial resources to spend time fulfilling legal requirements for registration. Thus, WUAs that are able to conduct this legal process are examples of associations with higher levels of organization (Murtinho et al. 2013b). It is expected that WUAs that are able to register legally will be more likely to implement adaptation strategies.

4.6. Actors

Five variables are included to assess differences in users' characteristics. The first two variables serve as proxies to measure how WUAs mobilize resources (internal or external to the community) to implement adaptation strategies: size (number of water users, approximately the number of households in the association), and income (measured as the total money collected from water fees and divided by the number of users). It is expected that WUAs with higher income will be more likely to mobilize internal resources to implement adaptation strategies. Based on the earlier discussion, WUA size could have either a positive or negative relationship with the likelihood of implementing adaptation strategies.

The three remaining variables, WUA experience, leader education, and residency inside the community, are used to capture how WUAs and their leaders learn to implement adaptation strategies. It is expected that when there is the need to make changes, associations with higher experience (measured as the number of years the association has been distributing water) will have better institutional knowledge of how to make decisions. Leader education (number of years of formal education) is expected to facilitate how leaders understand the legal processes, how to submit projects, internal accounting, etc. One concern in some communities is that their leader does not reside inside the community (instead, some live in urban areas), so they do not experience the water shortage problems that the other members of their community experience (Murtinho et al. 2013b). Because of this factor, it is expected that WUA's with leaders living inside their community are more likely to learn through direct experience from the problems and create possible solutions, increasing the likelihood of implementing adaptation strategies. However, in other interviews, leaders argued that they have learned new water management strategies thanks to reside in urban centres, where water is managed by bigger public utilities.

4.7. Interactions

The last group of variables measures the interaction between the WUAs and the local governments. The first variable, request external support (percentage of the adaptation strategies for which the WUA formally requested support from the government or NGOs), shows the link between self-organization of the WUA and the local governments. It is expected that the WUAs that request external support (a process with relatively high transaction costs) will be more likely to be able to fund their adaptation strategies. A second variable, political connections (measured as the percentage of strategies where the WUA was successful receiving external support), assesses the likelihood of the WUA to obtain external support. Previous research shows that in the context of clientelist political systems, political connections influences the likelihood of success receiving financial support (Bardhan 1996; Murtinho et al. 2013b). It is expected that WUAs with more political connections will have better chances of getting financial support from external sources like municipal governments,[3] hence they will be more likely to implement more adaptation strategies.

5. Results and discussion

Table 2 illustrates the regression results to assess what facilitates adaptation to water scarcity changes. The models report how the socio-ecological-systems characteristics, including the socioeconomic settings, resource systems and units, governance, actors and interactions, influence adaptation.[4] The first model shows the results for the overall adaptation index, and models 2–4 report what facilitates adaptation for three subcategories of water management (micro-watershed, supply, and water demand strategies).

As illustrated in Table 2, socioeconomic settings appear to have a mixed importance facilitating adaptation. For example, municipal water investment was not significant in any model. This result could reflect the clientelist political system, where adaptation is more likely not in municipalities with higher

[3] As explained earlier, little water management support from NGOs exists in the region.

[4] The four models comply with OLS regression assumptions. Similar to previous studies on collective action and adaptation (Wheeler et al. 2013; Villamayor-Tomas 2014), the coefficients of determination (adjusted R^2) are relatively low.

Table 2: OLS regression results.

	Model 1	Model 2	Model 3	Model 4
Socioeconomic settings				
Municipal water investment	0.002	–0.002	0.008	0.006
Rural poverty	–0.018	–0.029*	0.005	0.021
Rural population density	–0.003	–0.005	–0.001	–0.005
Resource systems and units				
Summer rainfall	–0.078**	–0.057	–0.057	–0.161***
Land cover change	–0.008**	–0.010**	0.001	0.007
Governance systems				
Legal registry	0.244	–0.031	0.390*	0.268
Actors				
WUA size	0.000	0.000	0.002**	0.002**
WUA income	0.024	0.044	0.019	0.261***
WUA experience	0.029***	0.014	0.023**	0.014
Leader education	0.002	–0.011	0.033	0.007
Leader resides inside community	0.238	0.363	–0.166	–0.481*
Interactions				
Request external support	2.829***	2.688***	0.378	0.281
WUA political connections	0.497**	0.376	0.481**	0.003
Constant	0.831	1.560	–0.327	3.591*
Adjusted R^2	0.553	0.358	0.198	0.205

N=104. Table shows regression coefficients. *p<0.1, **p<0.05, ***p<0.01.
Dependent Var: Model 1 (Overall Adaptation Index), Model 2 (Micro-Watershed Strategies), Model 3 (Water Supply Strategies), and Model 4 (Water Demand Strategies) Index.

government investment, but where WUAs are organized, request funds, and have the political connections to obtain funding (see below the governance and interactions variables).[5] This finding implies that in a clientelist system, policies that increase local funding to invest in water management not necessarily will benefit all WUAs (Flórez 2005; Murtinho et al. 2013b). It would be possible, that those WUAs with low self-organization to request funds and lack of sufficient political connections to get them, could be isolated from government support, perpetuating their vulnerability to current and future environmental changes (and reflecting the possibility of poverty traps) (Lemos et al. 2013). In addition, rural poverty was only significant in the micro-watershed management model. WUAs located in municipalities with higher poverty tend to implement fewer micro-watershed adaptation strategies. This could reflect that strategies such as land purchases require higher investments that relatively poorer communities cannot afford (Murtinho et al. 2013b), and in addition, some WUA leaders argue that these are relatively newer strategies to deal with water scarcity that very poor communities might not be willing to experiment with. Further research is needed

[5] Organized WUAs (measured as having legal registry or request external funds) does not necessarily have high political connections (there is low correlation among these variables, see the appendix, table 2).

to fully understand the relationships between poverty and the implementation of different strategies. Finally, rural population density was not significant in any model. Given that other studies in the Andean region show that demographic pressure is an important factor to explain water availability (Buytaert and De Bièvre 2012), it appears that rural population density is not a good proxy for water demand.

Results from this study show that the two environmental variables that try to measure disturbances in water availability, land cover change and summer rainfall, are statistically significant. WUAs located in municipalities with decreasing land cover are more likely to implement adaptation strategies, specifically those strategies designed to improve the micro-watershed conditions. Previous research in Fúquene shows that municipalities with lower percentage of ecosystems that regulate water flow, such as páramos and forests, are correlated to areas with higher water scarcity (Murtinho et al. 2013a). In consequence, it was expected that in areas with higher loss of these ecosystems (increasing the likelihood of water scarcity), WUAs will try to implement micro-watershed strategies such as land purchase, reforestation, establishing fences to protect the water source, etc. In addition, WUAs that face relatively drier summers are also more likely to adapt, especially implementing strategies to reduce water consumption. As explained earlier, in Fúquene, WUAs perceive higher water scarcity and more crisis events (due to El Niño) in areas with relatively drier summers (i.e. higher seasonal rainfall variability) (Murtinho et al. 2013a). Although it is expected that WUAs in areas with relatively drier summers are more likely to adapt, it is not clear why this variable is not significant in the micro-watershed and supply management strategies models. Lastly, neither land cover change nor summer rainfall were significant in model 3. During interviews with the WUA leaders, they stated that all supply management strategies were adaptation strategies to deal with water scarcity. However, based on the results of model 3, it would appear that leaders are not implementing these strategies based on past changes in land cover and rainfall variability. Future research is needed to better understand why WUA leaders implement these supply strategies. Potential explanations include that WUAs are implementing these strategies in response to local governments' priorities on how to allocate water investments (Murtinho 2013), or that WUAs implement these strategies based on expected future rainfall and land cover changes.

Regarding the governance system, specifically WUAs official recognition to manage water, the study finds that legal registry is positively related to adaptation, particularly to implement supply water management strategies. This suggests that WUAs that are organized enough to bear the high transaction costs to officially register as a community-based organization are more likely to implement these strategies.

Table 2 also shows that some of the variables that characterize the WUAs are important for adaptation. First, WUA size in Fúquene has an important variation, from 12 to 575 households, and this study finds that size has a significant positive influence on the likelihood of implementing water supply and demand adaptation strategies. As in previous research (Poteete and Ostrom 2004), this result suggests that it is easier for bigger WUAs to obtain internal and external resources to finance these adaptation strategies. In addition, results show that WUAs incomes' positive influence on adaptation is only statistically significant in the water demand model. This could suggest that WUAs internal financial resources are relatively important to implement water demand strategies, while for watershed and water supply strategies, internal resources are less important (possibly, WUAs rely more on external funding, where requesting funds and political connections are relatively more important factors, see below).

As expected, and similar to previous studies of collective action for water management (Dayton-Johnson 2000; Fujiie et al. 2005), this study finds that WUAs' years of experience managing the resource and dealing with water problems influence the likelihood of adaptation. This could suggest that older WUAs had more time to learn how to coordinate their internal interests and how to search for external funding. Further, from the two characteristics of the leaders that also try to capture how learning facilitates adaptation, education level and place of residency, only place of residence was significant in model 4. Results suggest that leaders who do not reside in their communities are more likely to implement water management strategies. Possibly, these leaders have had experience living in urban centres (inside or outside the watershed) were all households pay their water bills depending on actual water consumption (one of the water management strategies that WUAs try to implement). Future research is needed on how to measure the complex processes of learning and knowledge utilization in adaptation (Pahl-Wostl 2009; Baird et al. 2014).

Finally, the study shows that the last group of variables, the interactions between WUAs and local governments, also facilitates adaptation. As expected, regression results show that WUAs that are organized enough to be able to afford relatively high transaction costs to formally request external financial support from local municipalities are also able to implement more adaptation strategies. However, as explained earlier, in a clientelist political system, municipal investments are not equally distributed among communities. Thus, in addition to requesting funds, specifically for water supply strategies, Table 2 shows that having political connections to receive funding also facilitates adaptation. This could reflect the political preferences of local governments who favour investments in big infrastructure (i.e. water tanks) that could attract more future voters (Murtinho 2013; Murtinho et al. 2013b).

6. Conclusion

In many regions of the world, including the Andes, climate change is expected to cause more frequent periods of water scarcity (Vera et al. 2006; Kundzewicz et al. 2007). The study in Fúquene, Colombia, shows how communities collectively mobilize to adapt to changes in water scarcity. Similar to the common-pool resource literature on water management (Dayton-Johnson 2000; Meinzen-Dick et al. 2002; Fujiie et al. 2005), results from the regression analysis show that the water association's management experience and learning, income and poverty levels, number of users, and water availability significantly influence collective action to implement adaptation strategies. However, as discussed by Marschke and Berkes (2006) and Villamayor-Tomas (2014), environmental changes beyond normal variability might present new challenges for collective action. This study explicitly examined the conditions that influenced the ability of water associations to adapt to perceived changes beyond normal variability. The results indicate that additional external factors may influence the collective decision-making processes. Specifically, this study suggests 1) the importance of explicitly linking environmental disturbances to decision-making, 2) the critical role of external financial support to adapt, and 3) the need for future studies that explicitly consider actions and outcomes of collective action in the context of environmental change.

First, these results indicate that not all adaptation strategies are directly in response to previous environmental change. Using quantitative and qualitative methods, this study distinguished adaptation strategies that are directly linked to environmental changes from those strategies that were undertaken despite no apparent previous environmental change. Results show that to reduce water scarcity, communities located in areas with higher deforestation rates in the last few decades are more likely to implement watershed adaptation strategies (such as purchasing land and reforestation projects), while those that have relatively drier summers are more likely to implement water demand strategies. In addition, results show that WUAs are implementing water supply strategies (i.e. building water tanks) without facing previous environmental changes, suggesting that further research is needed to better understand how other possible factors influence their decision-making, such as WUAs perceptions of future environmental changes and the investment preferences of local governments.

Secondly, the study highlights the important role that external actors may have in shaping adaptation. In many cases, WUAs perceive that they require external financial support to implement more expensive adaptation strategies such as land purchase and reforestation projects, or reservoirs, strategies that would often cost 10 or 20 times the association annual income (Murtinho et al. 2013b). The regression results in this study show that the amount of municipal water investment is not significantly associated with WUAs adaptation, highlighting that in the context of a clientelist system, adaptation is more likely not in municipalities with higher government investment, but where other factors are present. These key additional factors necessary to adapt to environmental change include: officially being recognized as a community based organization, WUAs organization to request funds to the government, and the presence of political connections with the government to ultimately acquire those funds.

Finally, the findings identify important areas for future research. The research presented in this paper examined the intention to adapt in 2008 regardless of the actual success of the adaptation strategies taken by WUAs. Future research is needed to gather current data to assess new socioeconomic and environmental changes, and evaluate the success of these adaptations in terms of water availability and quality, changes in livelihoods, economic efficiency, and the distribution of costs and benefits among households and communities. This demands further quasi-experimental longitudinal studies to analyse the impacts of different adaptation strategies and trace the links between disturbance and adaptation. By conducting these and other rigorous field studies, scholars in our field will be able to develop more robust theories of adaptation that can be used to guide policies for facilitating adaptation.

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APPENDIX

Table 1: Index weights (based on Principal Component Analysis).

	Overall Adaptation Index	Watershed Strategies Index	Supply Strategies Index	Demand Strategies Index
Land Purchase	0.671	0.564		
Reforestation	0.673	0.776		
Fences	0.495	0.707		
Report	0.513	0.592		
Tanks	0.294		0.218	
Treatment Plant	0.215		0.776	
Reservoir	0.351		0.629	
New Sources	0.212		0.581	
Pipes	0.501			0.311
Capacity Building	0.058			0.635
Prices	0.000			0.778
% of variance explained by 1st component	17.876	44.273	34.583	36.812

Note: The Overall Adaptation Index has a relatively low percentage of variance explained by the first component. Other components also explain some of the variability, but only the first component has positive coefficients. This result is similar to previous studies (Vyas and Kumaranayake 2006), and could be explained by the relatively higher number of variables used in the analysis (Vyas and Kumaranayake 2006).

Table 2: Correlation among independent variables.

	Municipal Water Investment	Rural Poverty	Rural Population density	Summer Rainfall	Land cover change	Legal registry	WUA Size	WUA Income	WUA experience	Leader education	Resides	Request external support	WUA Political connections
Mun. Water Inv.	1.000												
Rural Poverty	–0.666	1.000											
Rural Pop.density	0.426	–0.413	1.000										
Summer Rainfall	0.259	–0.323	–0.010	1.000									
Land cover Ch.	0.663	–0.437	0.053	0.159	1.000								
Legal registry	–0.214	0.065	–0.162	–0.140	–0.167	1.000							
WUA Size	–0.222	0.081	–0.008	0.066	–0.254	0.274	1.000						
WUA Income	0.147	–0.321	0.111	0.320	0.008	0.153	0.101	1.000					
WUA experience	0.173	–0.283	0.284	0.127	0.004	–0.147	0.118	0.034	1.000				
Leader education	0.036	–0.221	0.110	0.036	0.014	0.226	0.234	0.286	–0.049	1.000			
Resides	0.134	0.002	0.015	–0.064	0.189	–0.030	0.070	–0.209	0.091	–0.267	1.000		
Request external	–0.035	0.131	–0.025	–0.072	–0.022	0.234	0.138	–0.056	–0.020	0.016	–0.035	1.000	
WUA Political	0.042	–0.039	–0.012	0.080	0.051	–0.132	0.132	–0.100	0.062	0.066	0.026	0.313	1.000