Understanding Adaptation to Climate Variability: Challenges and Opportunities of Community Based Water Management [1]

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ABSTRACT

This study explores how Water User Associations adapt to water source degradation due to climate variability and land use changes. Specifically, the article investigates the factors that determine whether local Water User Associations take measures to manage their water and micro-watersheds in order to adapt to the degradation of their water resources. This article presents an analysis of the water management decisions and the characteristics of 111 Water User Associations in 15 municipalities of the Fúquene watershed in the rural Andes of Colombia. Specifically the article analyze how environmental, socio-economic , institutional and psychological factors influence the implementation of the associations' adaptation strategies. Using qualitative and quantitative methods, the article results show how and why factors at two different levels (the associations' and the broader context) impact the decision of the associations to adapt to changes in water conditions.

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1 Introduction

In the Andean region of South America, understanding local governance is particularly important for watershed management as many rural communities receive minimal government support for water management and the communities themselves must decide if and how they will protect their watersheds and distribute their water. In Colombia, for example, only 9% of the rural population has access to safe drinking water, and only about half has access to any water distribution system at all (USAID and MAVDT, 2005). In many Andean communities of Colombia, autonomous water associations have emerged in the absence of outside intervention to solve conflicts of water distribution due to increasing water demand and water shortages in the dry seasons (Peña et al., 2007). In 2005, water associations provided water to almost half the Colombian rural population (approximately 4.5 million people) (Colmenares and Mira, 2007).

The water management decisions of these associations and the respective residents may be pivotal in determining whether Andean communities will have continued access to freshwater. In the Andes, appropriate management of páramos (high altitude ecosystems), forests and river systems is necessary to provide an adequate supply of water for many rural Andean communities. Páramos and forests serve to reduce water peak flows and to sustain a base flow during dry seasons (Buytaert et al., 2006, Harden, 2006, Murtinho, 2009). In many regions, however, these ecosystems are threatened by increasing population density and its associated agricultural economic activities (Ortiz et al., 2005). Given these changing demographic, economic and environmental conditions, and the relative autonomy of water management in many communities, a critical concern for international development policy is whether communities are able to address water source degradation by themselves, and if so, under what conditions.

Previous research highlights certain characteristics such as socio-economic and organizational factors that have been found to facilitate collective action to manage local resource systems, including water systems (Agrawal, 2001, Bardhan, 2000, Meinzen-Dick et al., 2002, Ostrom, 1990). Much of this research, however, has focused on resource management in communities that have remained relatively buffered from demographic, political and market change. While some researchers examine how resource users collectively mobilize to address external change (Hayes, 2008, Ostrom, 2008, Richards, 1997, Smit and Wandel, 2006, Perreault, 2005, Bebbington, 1993), we have yet to identify key factors that facilitate adaptation.

This article explores the factors that determine whether local Water User Associations (WUAs) take measures to manage their water and their micro-watershed in order to adapt (or not) to the degradation of their water resources. Specifically, the study comprises the following analyses: 1) the different adaptation strategies that communities are implementing to adapt to water source degradation, 2) the changes (environmental and socioeconomic) that communities are adapting to, and 3) the broader contextual factors and the associations' characteristics that facilitate (or impede) the implementation of their adaptation strategies.

To answer these questions, this article investigates water management in rural communities in the Fúquene watershed, located in the eastern Andes of Colombia. Fúquene is a an ideal site because it is representative of socio-economic and environmental processes occurring throughout the Andes with respect to local water management. Similar to many Andean regions, water from the watershed is salient to all households in the region

(CAR, 2006); when the water supply is scarce or has deteriorated, there are few or no other sources for consumption. Furthermore, as in many regions of Colombia, in Fúquene, rural communities have created WUAs, to autonomously distribute and manage water with relatively low support from local and regional governmental authorities (CAR, 2006).

Government agencies and non-governmental organizations (NGOs) in developing countries such as Colombia require better information on how and where to allocate scarce resources to increase the capacity of local communities to adapt to changing environmental conditions such as climate change. This study tries to contribute to fill this gap by providing a hybrid agency and structure approach (Chowdhury and Turner, 2006) to understand local communities' decisions to adapt. Analyzing the structure, or the institutional, socio-economic and environmental contextual factors that communities face, is important because we need to better understand what exactly communities are trying to adapt to (Smit et al., 2000, Murtinho and Hayes, 2008), and how the broader context influences their behavior (Perreault, 2005, Wilder and Lankao, 2006). In many cases, there is not just one factor that is changing (i.e. climate), but a combination of different types of contextual factors that shapes communities' decisions (Marschke and Berkes, 2006, Eakin, 2005). If we want to design policies to increase the adaptive capacity of local communities, we need to clearly understand how these disturbances or contextual changes are linked to communities' responses. However, understanding the structure or broader context and community responses is not enough to fully understand how communities might cope with changes. We also need to study the community level governance characteristics. Specifically for Colombia, we need to focus in the characteristics of the WUAs, since these associations are the "agents" that make the water management decisions and represent the households interests. Understanding WUAs characteristics is crucial since the same socio-economic or environmental context in a region can generate different responses due to WUAs' diversity in their capacity to adapt (Chowdhury and Turner, 2006).

In the following section, the article presents the theoretical framework to understand adaptation for community-based water management. This is followed by a description of Fúquene's environmental, socioeconomic and governance characteristics and the methods used in the analysis. Later, in the results and subsequent discussion, there is an analysis of the environmental and socio-economic changes that communities are facing, the adaptation strategies that they are implementing and how the contextual and community level characteristics influence their decisions to adapt.

2 Conceptual model to understand adaptation in Common-Pool Resource Systems

In the last decade, scholars have included in their research a hybrid agency and structure approach to understand the human dimensions of environmental change (Carr et al., 2008, Chowdhury and Turner, 2006, Eakin, 2006, Vasquez-León and Liverman, 2004). Much of this research, however, focuses on farmers´ individual land-use decisions and how individual characteristics and contextual factors influence their behavior. Unlike most farming decisions, where each family can privately decide when and how to change their practices given the contextual restraints or opportunities[2], water is a common-pool resource. A common-pool resource (i.e. water, forests, fisheries) is a type of good that

[2] An exemption could be farming cooperatives which also require collective decision-making.

presents difficult and costly exclusion and subtractability (once and individual gain access, the resource units that they harvest are not available for anyone else's use) (Schlager, 2002). Water requires collective decisions in order to be managed. A single individual response or adaptation will prove insufficient to solve with the watershed problems.

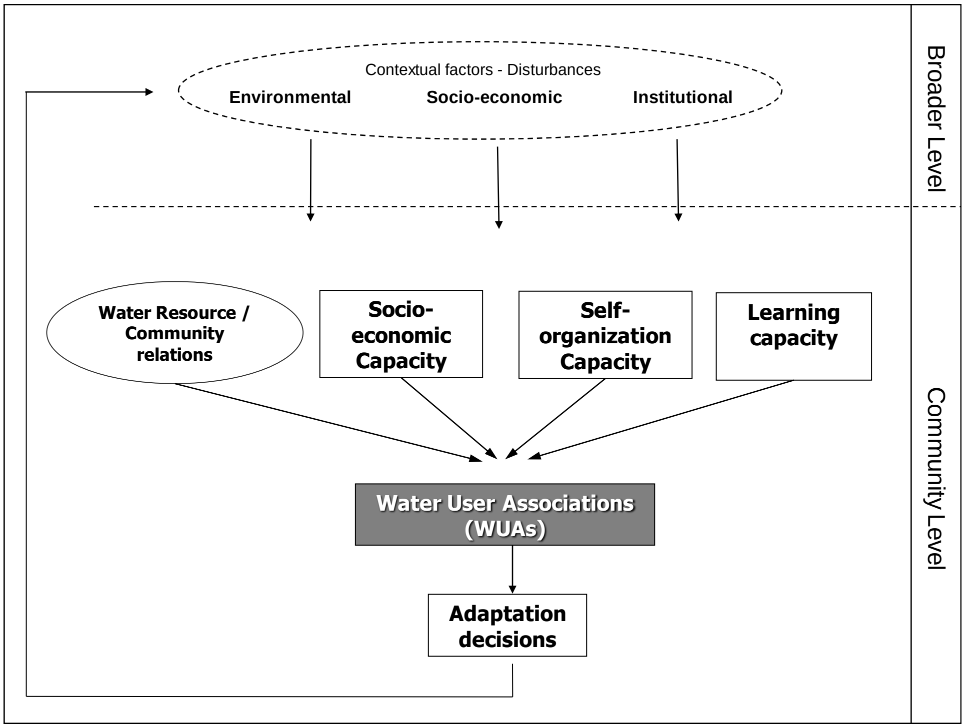
The commons literature provides theories to understand not just individual decisions but also collective decisions, requiring cooperation and coordinated action. It emphasizes the analysis of institutional variables and other factors that may contribute to cooperation. Ostrom's research, for example, focuses on individual and collective behavior, and it explicitly includes structural political and economical contextual factors that shape human decisions (Ostrom, 2005). With respect to resource management, findings from the commons literature identify how particular socio-economic and organizational characteristics, such as leadership or social interactions in a community, facilitate successful governing of local communal resource management (Agrawal, 2001, Bardhan, 2000, Meinzen-Dick et al., 2002, Ostrom, 1990). In recent years, the literature on communal resource management has begun to explore how communities adapt to uncertainty due to changing environmental and socio-economic conditions (Berkes et al., 2003, Janssen and Ostrom, 2006).

In this study, adaptation is defined as a conscious process or action in a system in order to respond to a current or predicted environmental, socio-economic or institutional disturbances (Murtinho and Hayes, 2008, Ford et al., 2007, Nelson et al., 2007, Smit and Wandel, 2006). Some scholars argue that there is the possibility that communities will not adapt "well" or will "maladapt". Some adaptations might unintentionally cause greater damage than good by protecting just certain resources, benefiting only some members of a community, or reducing vulnerability in the near term at the expense of greater vulnerability in the long term (Batterbury and Forsyth, 1999, Grothmann and Patt, 2005). In this study, adaptation strategies at least should be intended to be successful or reduce present and future vulnerabilities, although there is no guarantee that the actual outcome will achieve this goal.

2.1 Key factors that shape adaptation decisions

Research on governing the commons and adaptation has highlighted certain characteristics that influence the collective decision-making and management of common-pool resources like water. These studies reveal the following five broad categories at two levels: broader contextual level (the structural environmental, socioeconomic and institutional characteristics beyond the community or WUA) and community level characteristics (resource/community relations, self-organization, socio-economic and learning capacity) (see figure 1):

Figure 1: Conceptual model. Factors that shape adaptation



<u>Broader contextual factors</u>: At the broader level (outside the community), exogenous factors include: environmental (i.e. climate change), socio-economic (i.e. demographic changes) and institutional (i.e. water regulation) (Burton et al., 1993, Eakin, 2005, Janssen et al., 2007, Perreault, 2005). These contextual factors can influence communities' decisions in two ways: first, environmental, socio-economic and institutional changes can be the disturbance that communities respond to. 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, Olsson and Folke, 2001). In addition, socio-economic disturbances can spark adaptation (Eakin, 2006). For example, demographic changes can lead to increasing demand of natural resources, motivating communities responses (Coulthard, 2006). Adaptation can also being sparked by institutional change such as alteration of resource access rules (Gautam and Shivakoti, 2004, Janssen et al., 2007). The second way contextual factors can influence communities decisions is by indirectly shaping their capacity to adapt (in terms of the self-organization, socio-economic and leaning capacity). For example, a region's socio-economic characteristics and institutional context (i.e. infrastructure investment, markets, wealth and income levels and how they are distributed) can provide opportunities or challenges for communities' capacity to adapt (Eakin and Lemos, 2006, Eakin, 2005).

<u>Resource/community relations:</u> Some scholars emphasize the importance of the relation between the managed resource (i.e. water) and the user group or community in the type of decision taken regarding the resource (Agrawal, 2001, Ostrom, 1990). These relations include the perception communities have about the resource, the dependence of the community in the resource, and how the resource is used. For instance, in addition to the actual magnitude of contextual factors changes, perceived resource scarcity is

considered by many to be a key factor that influences the creation of resource management rules and strategies to manage communal resources (Berkes and Turner, 2006, Gibson and Becker, 2000, Olsson and Folke, 2001, Grothmann and Patt, 2005). In addition, the geographical location of water sources might influence adaptation. Communities located in the lower parts of a watershed might have to make "deals" and negotiate investments with communities in the upper parts of the watershed to gain control over water resources (Lebel et al., 2005).

Self-Organization capacity: Previous studies have shown that self-organization is an important characteristic for adaptation and to manage communal resources (Ostrom 1999; Carpenter, Walker et al. 2001; Olsson and Folke 2001; Berkes and Turner 2006; Lebel, Anderies et al. 2006). In this study, self-organization is understood as the ability of a water user group to adjust their functioning when facing social or ecological changes (Ostrom, 1999, Berkes and Turner, 2006). A self-organized group does not need to be completely self-sufficient, but has to be able to autonomously create and modify their rules to manage the water resource (i.e. rules to distribute water, impose sanctions to water users, change the fee system)(Ostrom, 1999). In the governance context of Colombia, a critical issue is the interaction between the government and communities to mobilize financial resources. One of the barriers to these cross-scale interactions is the relatively high transaction costs (i.e. legal requisites, paperwork, contracts)(Adger et al., 2005). Only well organized associations have the capacity to learn how to bear with these transaction costs in order to request external financial resources.

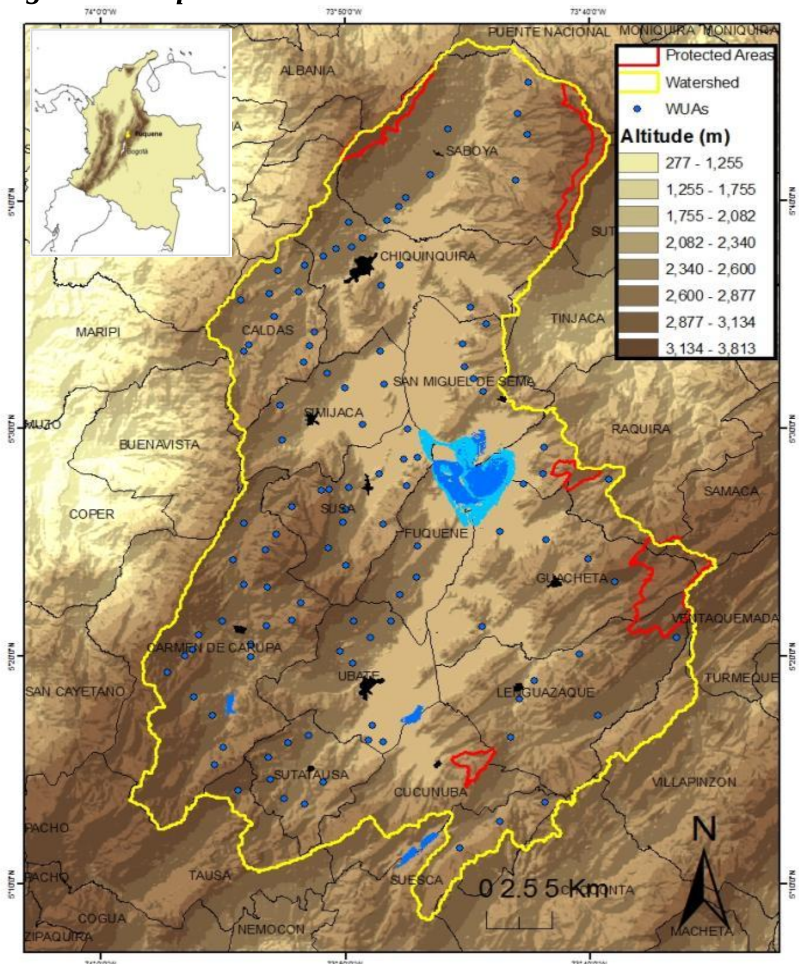
Socio-economic capacity: Studies have shown the importance of the ability to mobilize internal or external financial resources to have access to appropriate infrastructure and technology in order to be able to assume the costs of the adaptation strategies (Grothmann and Patt, 2005, Ivey et al., 2004, Pretty and Ward, 2001, Smit and Pilifosova, 2001). Key factors that allow communities to mobilize resources are: social networks among communities and political connections with the government (Pretty and Ward, 2001, Ivey et al., 2004), and communities' income and wealth levels (Grothmann and Patt, 2005, Smit and Pilifosova, 2001). In addition, size is an indirect community characteristic that influence the socio-economic capacity to adapt. Relatively bigger associations might have more resources in order to invest in adaptation strategies (Poteete and Ostrom, 2004), however smaller communities will be able to build trust relations, cooperate and manage communal natural resources more easily, including water systems (Agrawal, 2001, Bardhan, 2000, Fujiie et al., 2005, Meinzen-Dick et al., 2002, Poteete and Ostrom, 2004).

Learning capacity: Adaptation also arises when communities have had a long time of organizational experience with more opportunities to learn, either from previous experiences (trial and error responses) or from interaction with others like neighbors, NGOs and governmental agencies (Berkes and Turner, 2006, Carpenter et al., 2001, Folke et al., 2005, Lebel et al., 2006, Olsson and Folke, 2001). The education level of community members has also been shown as an important factor that influences collective action (Meinzen-Dick et al., 2002).

3 Study site: Fúquene Watershed

The study site is located in the watershed of the rivers Ubaté and Suárez in Colombia, known generally as the "Fúquene watershed". Fúquene, has an area of 198,000 ha and is located in the northern part of the eastern mountain range of the Andes, about 100 Km north of Bogotá (see figure 2).

Figure 2: Fúquene watershed location



3.1 Environmental characteristics

The lower part of the watershed, where the valley and a lake are located, has an elevation between 2400m and 2500m above sea level. Mountains surround this valley reaching their highest point at 3,750m (see figure 2). The average rainfall in the watershed is 905mm a year. It has a bi-modal rainfall regime with 6 months of relatively drier season or "summer" (32% of total annual rainfall). As most Andean regions in Colombia, the watershed is not high enough to have glaciers or snowpack to store water in the dry seasons. Rainfall is not equally distributed in the watershed. The northern part of the watershed has higher rainfall in both wet and dry season than the southern region. However, rainfall distribution along the year is less homogenous in the northern part.

In 2005, only 16,9% of the Fúquene territory was covered by native and partially intervened ecosystems (Murtinho, 2009), including strategic water regulators such as páramos and forests (Buytaert et al., 2006, Harden, 2006).

3.2 Socioeconomic characteristics

Fúquene has 16 municipalities. The rural population of these municipalities is approximately 115,000 inhabitants; this represents 55% of the watershed's population (DANE, 2005). The inhabitants are distributed in 147 communities or *veredas,* with an average rural population density of 49 habitants/Km^2 (CAR, 2006).

The main economic activity of the region is cattle ranching, agricultural activities and small scale coal mining. As in other regions of the Colombian Andes, land is privately owned, however, there are great differences in land distribution that are associated with differences in wealth. The most productive land is located in the irrigated systems in the valley; land is concentrated in a few families and is owned mostly by people from Bogotá. In contrast, land in the upper areas is where most of rural inhabitants live. This study focuses in these upper areas, where the land is the least productive with no irrigation systems, and it is owned by local families that usually have no more than 2 Ha (pers. comm., Fundación Humedales, 2007).

Poverty levels (measured as percentage of rural population with "Unsatisfied Basic Needs - NBI") in 2005 varies across the watershed from 25% of the population in some southern municipalities to more than 50% in the north and east of the watershed (DANE, 2005).

3.3 Water Governance Characteristics

In Colombia, water distribution is traditionally administered by municipal public water utilities. Due to lack of technical and financial resources, however, public utilities generally provide water only to urban centers and the urban periphery (Colmenares and Mira, 2007). In 2005, 92% of the urban population had access to a public water distribution system in contrast to just 22% of rural population (USAID and MAVDT, 2005, Colmenares and Mira, 2007). For this reason, 41% of the rural population have created their own communal water distribution systems (Colmenares and Mira, 2007). In 1994, a national law legalized communal water associations' right to distribute water.

In Fúquene, the purpose of these associations is to distribute water for household consumption, although in most cases without the appropriate water purification systems. In addition, some WUAs allow the use of water for cattle consumption, and in rare cases for crop irrigation. In most cases, WUAs capture the water from small creeks (in some cases they get water from rivers or directly from water springs). WUAs are autonomous in their decisions and they elect their own leaders or water managers. Usually, they have assembly meetings once a year where they make the important decisions (investments, rules changes, price system changes, etc.), the annual budget is revised and the directive board is elected (approximately every 2 or 4 years). Operational decisions are made by the president of the directive board (the WUA leader). WUAs' operational activities and in some cases infrastructure investments are funded by households' water consumption fees. In other cases, local governments support WUAs' investments. Usually the government helps with funding for materials and the WUA provides the rest of the costs and community labor. For some well organized WUAs, requesting external support is not enough to find external resources; political affiliation or connections with local authorities may be needed to negotiate financial resources. Some WUA leaders report that they usually support one of the candidates in the municipal elections, and in exchange they receive financial resources for communities' water projects (pers comm, WUA leaders 2008). In other cases, leaders state that they requested external funds to local authorities, but they did not want to establish direct contact with them. They state that they preferred to be "outside politics" or avoid possible corruption problems, even though they recognize that it greatly reduces their chances of finding support for their projects (pers comm, WUA leaders 2009). In Fúquene, there is not much support besides financial resources for infrastructure investment. Most of the associations have not received water management training (or informal education) from the government, and none of them have had any training from nongovernmental organizations (NGOs).

In Colombia, several governmental agencies, operating at different jurisdictional scales, are responsible for water conservation (see table 1). At the regional level, the Regional Autonomous Corporation (CAR) is the agency in charge of implementing the national environmental policies in the Fúquene watershed. Some of CAR responsibilities include: provision of water use permits and regulation (including sanctioning) to prevent deforestation and contamination activities. Although small local projects have been implemented, there are not enough financial resources and political desire to fully implement the watershed management plans (pers. comm., Fundación Humedales, 2007).

At the local scale, municipal authorities are in charge of coordinating efforts with the CAR in order to protect water resources (see table 1). In addition, they have to invest in rural development, including investing in water management infrastructure, usually by supporting WUAs needs (water tanks, distribution networks, etc.). In Colombia, most of local government financial resources comes from transfers from the national government. The amount of these transfers depends on the municipality fiscal efficiency and their socio-economic characteristics (DNP, 2008). In Fúquene, rural investment levels varies among municipalities, from a 5-year average of US$74,000 in the northern part of the watershed, to more than US$390,000 in other regions (DNP, 2008).

Table 1. Governance characteristics in Fúquene

	Water Management	**Environmental Management**	**Financial Resources**
National Gov	Designs policies	Designs policies	National Budget
Regional Gov (CAR)	- Water permits (should monitor appropriate use of water)	- Implement policies - Watershed management plan - Should monitor and sanction	CAR Budget and National transfers
Local Govs (16 Municipalities)	- Urban: water distribution - Rural: support WUAs with water infrastructure investments	- Should coordinate with CAR to implement national policies/watershed plans	Mostly transfers from national government
Communities (128 Water User Associations - WUAs)	- Water distribution to households - Should follow policies - Autonomous decisions	- Should follow policies - Autonomous decisions	- Operational activities: households fees - Infrastructure: households and municipality

4 Methods

This article is based on data gathered in 12 months of fieldwork between 2007 and 2009 using different quantitative and qualitative methods. Socio-economic information includes: public investment and demographic data bases (DANE, 2005, DNP, 2008), semi-structured interviews to key informants, and structured interviews to the leaders of the 111 Water User Associations of the Fúquene watershed[3]. In addition, environmental information includes: land cover-land use maps from 1987 and 2005 (scale 1:100,000) (IAvH, 2007) and daily rainfall data between 1962 and 2006 for 13 stations inside the watershed (CAR, 2008).

Ideally, due to the temporal nature of adaptation, this study should be able to track water scarcity changes and how communities respond to these changes in a longitudinal data set. Unfortunately, although there is information on how the contextual factors (environmental and socioeconomic) have changed over time, there is no information on the adaptation strategies and WUAs characteristics in previous years. Due to the lack of a base line, I was not able to contrast WUAs past characteristics with the information I collected during fieldwork. In order to minimize these challenges, I conducted semi-structured interviews to key informants to better understand the adaptation processes. For instance, in order to identify the adaptation strategies, I asked key informants how water associations dealt with changes in water scarcity. For each strategy identified, I asked why that strategy was used, in order to be sure that the strategy was consciously and intentionally used to respond to perceived actual or potential water scarcity (for a discussion see Murtinho and Hayes 2008).

4.1 Variable Selection and Data

In order to analyze the factors that influence the 11 identified adaptation strategies implemented by the WUAs, I aggregate the strategies in an index using principal component analysis[4]. Since strategies can be complementary (for example when an association purchases land for conservation they also tend to make reforestation projects), a simple sum of the strategies would not be appropriate for the aggregation (Fujiie et al., 2005). The factors that shape collective decisions to adapt is divided in two levels: 1) structure or broader contextual variables (measured at the municipal level), and 2) agency or community level variables (measured at the WUA). The hypothesized relations between the predictor variables and the adaptation index are summarized in table 2 for the contextual variables at the municipal level, and in table 3 for the community level variables. I selected variables that could be important to explain the initiative to adapt based in the results of semi-structured interviews to key informants, and previous econometric studies of the factors that influence cooperation in irrigation case studies (Bardhan, 2000, Dayton-Johnson, 2000, Fujiie et al., 2005, Meinzen-Dick et al., 2002). A plus or minus sign is

[3] 17 water associations were not included in the analysis: in 8 cases it was not possible to do the interviews. In 9 cases association were exceptional cases (they did not use superficial water sources or they were exceptionably big - more than 1300 users) that made adaptation strategies difficult to compare. In addition, for the regressions, 9 WUAs had to be excluded since their leaders answer "don't know" to some of the questions analyzed.

[4] To build the index, I used the first component vector of the normalized adaptation strategies variables (this component explains 18.05 of the variance)

assigned to indicate the anticipated direction of the relation between the predictors and adaptation. Each group of variables is described in this section.

Contextual level variables

Environmental variables: 1) *land cover change* is measured between 1987 and 2005, it includes native and partially intervened ecosystems (Murtinho, 2009). It is expected that loss of ecosystems as forests and páramos will motivate WUAs to take actions to protect their micro-watersheds. 2) There are no increasing or decreasing trends in Fúquene's total rainfall, distribution or frequency of dry events (Murtinho, 2009), so long-term trend variables were not included in the analysis. However, previous studies show that WUAs in municipalities with higher rainfall differences between seasons (lower *summer rainfall*) perceive higher water scarcity and crisis events (due to El Niño events) (Murtinho, 2009). It is expected that WUAs located in regions perceived as more exposed to El Niño events will implement more adaptation strategies.

Socio-economic variables: 1) *rural population change* between 1985 and 2005 is selected as a proxy of municipal water demand changes. It is expected that WUAs in municipalities with higher population growth will implement strategies to deal with increasing water demand. 2) *Rural poverty* (% of households with unsatisfied needs) can have mixed effects over adaptation. WUAs located in municipalities with high poverty levels could have more problems collecting users fees to implement adaptation strategies. However, due to poverty conditions, it is possible that these WUAs could also have higher support from municipal investment. 3) It is expected that WUAs located in municipalities that have higher *Municipal investment* in rural water projects will have more chances of receiving support to invest in adaptation strategies.

Institutional variables: This study does not include institutional contextual factors. Since all the WUAs are located under the same regional government jurisdiction (CAR), there is no clear variation among water or environmental regulations and policies that could influence adaptation decisions.

Table 2. Contextual level variables

Variable		Description	Expected	Mean	Std D.	Min.	Max.
Environmental	Land cover change	% of change 1987-2005	-	-16.28	24.12	-54.9	24.3
	Summer Rainfall	% of total annual rain	-	16.23	0.94	15.1	18.6
Socio-economic	Rural Population change	% of change 1985-2005	+	1.58	28.83	-37.58	59.40
	Rural Poverty	% of households	+/-	36.41	10.31	24.07	62.33
	Municipal water investment	5-year avg (thousands of $US)	+	169.16	72.74	73.76	390.39

Community level variables
Water/community relations: It is expected that the WUA leader perception of water scarcity will increase the chances of implementing adaptation strategies. Two variables are included: the current *water scarcity* in the summer season (measured in a scale of 1 to 5) and *water scarcity change* relative to 20 or 30 years ago (measured in a scale of 1 to 5). In addition, a variable of the *vertical location* (upstream or downstream) of the community relative to other communities in the watershed is included. It is expected that communities located relatively upstream in the watershed, will have fewer reasons to implement adaptation strategies, since there are no other upstream communities causing potential water degradation (pollution, deforestation, etc.).

Self-organization capacity variables: All WUAs are autonomous and have the ability to create and modify their own water management rules. However, WUAs differ in their ability to organize to adjust their activities according to the WUA necessities and external requirements. Two variables are included as proxies of these differences in organization: 1) *legal registry* (measures if the WUA is registered to be legally recognized as a community based organization) and 2) *request external support* (percentage of the adaptation strategies that the WUA formally requested support from the government or NGOs). These two activities have relatively high transaction costs and some WUA leaders do not have the knowledge or financial resources to spend time fulfilling legal requirements and submitting projects. WUAs that are able to conduct these activities are examples of associations with higher levels of organization (pers comm, WUA leaders 2008). It is expected that WUAs that are able to have legal registry and request more external support will have higher capacity to implement adaptation strategies.

Socio-economic capacity: three variables are used as proxies of the capacity of the WUAs to 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); *political connections* (measured as the percentage of strategies where the WUA was successful receiving external support); and *income* (measured as the total money collected from water fees and divided by the number of users). It is expected that bigger WUAs with higher income will have more capacity to mobilize internal resources to implement adaptation strategies. However, if WUAs are too big they could face more difficulties coordinating the processes of collective action needed to adapt. In addition, WUAs with more political connections will have better chances of getting financial support from external sources such as municipal governments.

Learning capacity: three variables try to capture the ability of the WUAs and their leaders to learn from their previous experiences. First, it is expected that associations with higher *experience* (measured as the number of years the association has been distributing water) will have better institutional knowledge on how to make decisions when there is the need to make changes. Second leader *education* (number of years of formal education) is expected to increase the ability of the leader to understand the legal processes, how to submit projects, internal accounting, etc. Third, one concern in some communities is that their leaders does not *live inside the community* (instead, some live in urban centers), so they do not experience the water shortage problems as the other members of their community (pers comm, WUA leaders 2008). It is expected that WUAs with leaders living inside their community are more likely to learn through direct experience from the problems and possible solutions, increasing the likelihood of implementing adaptation strategies.

Table 3. Community level variables

Variable		Description	Expected	Mean	Std D.	Min.	Max.
	Adaptation Index (dependent variable)	Score	n.a.	0.01	1.99	-3.50	5.79
Water / community relations	Perceived current water scarcity	1=medium to very high	+	0.52	0.50	0.00	1.00
	Perceived water scarcity change	1=higher	+	0.63	0.49	0.00	1.00
	Community vertical location	1=upstream	-	0.68	0.47	0.00	1.00
Self-organization	Request external support	% of total strategies	+	33.43	19.48	0.00	70.00
	Legal registry	1=yes	+	0.65	0.48	0.00	1.00
Socio-economic	WUA Size	# users	+/-	126.1	121.8	12.0	575.0
	WUA Political connections	%	+	60.90	36.36	0.00	100.0
	WUA Income	US$/month	+	1.19	1.11	0.00	6.37
Learning	WUA experience	Years	+	16.92	9.55	0.10	43.00
	Leader education	Years	+	8.37	4.87	1.00	16.00
	Leader resides inside community	1=inside	+	0.83	0.38	0.00	1.00

4.2 Analytical Methods

In order to analyze the community and contextual factors that influence the WUAs adaptation strategies, I use a multi-level model where level 1 is the WUA and level 2 is the municipality (Raudenbush and Bryk, 2002, Carr et al., 2008, Goldstein, 2003).
The specification of the two-level model is explained below:

$$Y_{ij} = \beta_{0ij} x_0 + \beta_{n1j} X_{nij} + \beta_m W_{mj} \quad \text{and} \quad \begin{aligned} \beta_{0ij} &= \beta_0 + u_{oj} + e_{0ij} \\ \beta_{n1j} &= \beta_{n1} + u_{1j} \end{aligned}$$

Where sub-index *i* represents level 1 and sub-index *j* is level 2. *Y* represents the adaptation index, X_n are the explanatory variables at level 1 (listed in table 2) and W_m are the explanatory variables at level 2 (listed in table 3). Finally, β are the unknown parameters, *m* and *n* are sub-index for the explanatory variables, and *e* and *u* are the random terms for level 1 and 2 respectively.

To compliment the multi-level models, I use ordinary least squares (to test linear relations), a logit model (to test non-linear relations, with all the variables transformed to binary variables), and bi-variate correlations (spearman rho coefficient to test bi-variate non-linear relations).

5 Results

5.1 What are communities adapting to?

According to interviews, WUAs are trying to adapt to water source degradation with the objective of sustaining water flow during the summer season and in some cases, to improve or sustain the quality of the resource. Currently, 51% of WUA leaders perceive that there are medium, high or very high water scarcity problems in the summer. During the wet season, 9% of WUAs cannot distribute water to their users every day. This problem gets worse during the dry season when 41% of the associations cannot distribute water every day.

According to 63% of WUAs, currently there is less water available compared to previous decades. They state that there are three main causes of the higher water scarcity: land cover changes, rainfall changes and higher water demand due to population increase.

Land cover change: Most WUA leaders (40% of them) argue that loss of native ecosystems in the last few decades is the main cause of higher water scarcity. A WUA leader in the east side of the watershed noted "Antes había más agua... es que no hemos cuidado el páramo" (there use to be more water... we have stopped taking care of the high altitude meadows) (pers comm WUA leader, 2008).WUA leaders' perceptions are corroborated with analysis of land cover maps. Between 1987 and 2005, the watershed has lost 23.3% of these ecosystems, especially in the north and east side of the watershed (Murtinho, 2009). Most of this area was replaced with agriculture, pasture and mining systems (CAR, 2006, Murtinho, 2009). Previous research find that in Fúquene municipalities with lower percentage of these ecosystems and higher rates of deforestation are significantly correlated to areas where WUAs are not able to distribute water every day during the summer (Murtinho, 2009).

Rainfall changes: 27% of leaders state that rainfall changes is the cause of higher water scarcity. One of them stated, "el clima esta loco, ya no llueve como antes" (weather is crazy, it doesn't rain as it used to be" (pers comm WUA leader, 2008). Research in Fúquene shows that there is no statistically significant changes in rainfall trends in the last 44 years, in its distribution along the year, or the frequency of dry events (despite some local leaders perceptions) (Murtinho, 2009). However, due to high rainfall difference between seasons, local communities perceive relatively higher water scarcity levels in the northern part of the watershed (Murtinho, 2009). In addition, El Niño warm ENSO events can reduce the average annual rainfall by 40%, thereby accentuating water shortages in the region (IDEAM, 2002). In the northern part of Fúquene for example, El Niño events in 1983, 1991 and 2003 produced very low rainfall levels in the summer months, and are events still remembered by local communities (Murtinho, 2009).

Demographic changes: Seven percent of the leaders argue that the increasing water scarcity is due to higher water demand due to population increase. The total population in the watershed has almost doubled from 1951 to 2005 (1.13% average annual growth). As in other parts of Colombia, there has been an urbanization process in the Fúquene watershed in the last 50 years (DANE, 2005). While the urban population has continually grown (3% average annual growth), rural population increased until the 1990s and has since decreased (DANE, 2005). This process is not the same across the watershed; in some municipalities rural population has increased from 1985 to 2005 more than 50% while in other has decreased by more than 20%. Besides increasing water demand, growing population density also threatens ecosystems loss (Ortiz et al., 2005).

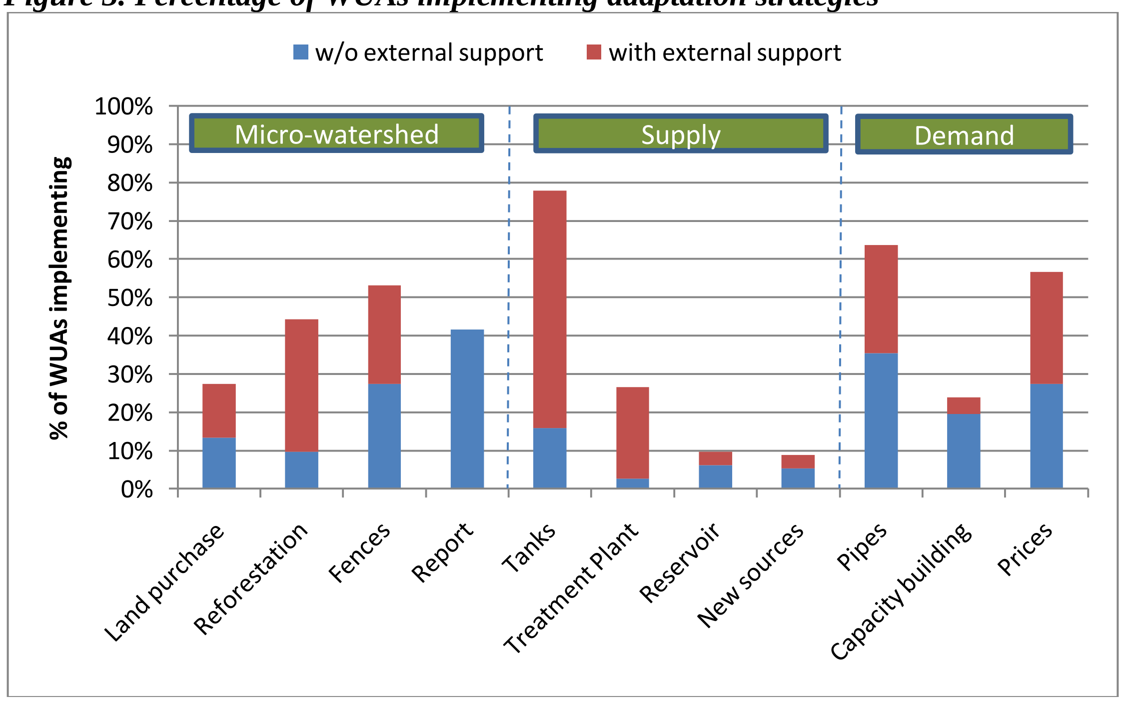
5.2 What are communities doing to adapt?

According to interviews, WUAs in Fúquene are implementing three types of strategies to adapt to water sources degradation: micro-watershed management, and supply and demand water management.

Micro-watershed management. The purpose of these strategies is to conserve and restore native ecosystems (páramos and forests) close to the water sources with the goal of protecting the water resource (in terms of quality and quantity). To do this, WUAs *purchase* upstream land to create informal protected areas, carry out small scale *reforestation* projects, and build fences to keep out cattle from the water source. In addition, WUAs *report* cases of inappropriate activities near water sources (i.e. use of agrochemicals, cattle ranching, etc.). Figure 3 shows that from these four strategies the most common activity is to build fences. In half of the cases, purchasing land and building fences was implemented without any external support (using community resources).

Water supply management. The objective of these strategies is to increase or keep constant the safe-drinking water supply. These strategies include[5]: upstream water *tanks*, water *treatment plants*, *reservoirs*, and establishing new systems to collect water from alternative *sources* (wells, or different creeks or rivers). The most common strategy is building water storage tanks (almost 80% of WUAs). Reservoirs and alternative water sources are the least used adaptation strategies. This reflects the high costs of building reservoirs and the lack of other alternative water sources.

Figure 3. Percentage of WUAs implementing adaptation strategies



[5] All the strategies analyzed in this article are collective. In addition to collective water tanks, many households use small water tanks in their homes (1 cubic meter of capacity). In the same way, some households build small reservoirs en their properties (for personal use).

Water demand management. The purpose of these strategies is to decrease the waste of water. These strategies include: improvement of water distribution network (*pipes*), informal *capacity building* programs among users to save water, and new *price* systems rules. More than half of the WUAs have installed water meters in the houses, so they can restrict consumption to certain levels, and in some cases to charge a price that varies according to the actual consumption.

5.3 What facilitates adaptation?

Table 4, shows the results of three regression models to determine how the municipal contextual factors and the community characteristics influence the number of adaptation strategies implemented by the water associations.

As shown in table 4, the first model estimated is a multi-level model including community level variables (the first level), and in addition, a second level random intercept to test the influence of the municipal level contextual factors. Results show that the second level intercept of the multi-level model is not significant. In addition, the variance explained by the second level is only 0.035%, suggesting that variance in the model is better explained with only the community level variables. Since there is such a low second level variance, when including the other contextual factors variables (land cover change, summer rainfall, rural population change, rural poverty, and municipal water investment) the model does not converge and confidence intervals cannot be estimated.

Although the multi-level model shows that municipal contextual factors are not directly explaining differences in adaptation among the associations, bi-variate analysis does show significant relations between the contextual factors and community level explanatory variables. As expected, high poverty levels in a municipality is significantly correlated to lower WUA income and lower leader education level. Furthermore, high poverty levels is significantly correlated to WUAs that requested relatively more external support.

Table 4: Regression model results. Dependant variable: Adaptation Index

		Multi-level model		**Linear model (OLS) (1 level)**		**Logit model [(1)] (1 level)**	
Variable		**Coef.**	**p-val**	**Coef.**	**p-val**	**Coef.**	**p-val**
	Random intercept (municipal level)	0.068	0.681	n.a.	n.a.	n.a.	n.a.
	Intercept (WUA level)	-2.980	0.000**	-4.735	0.000**	-4.198	0.002**
Water/community relations	Perceived water scarcity	0.555	0.069	0.589	0.048*	0.761	0.134
	Perceived water scarcity change	0.178	0.557	0.151	0.619	0.361	0.508
	Community vertical location	-0.167	0.601	-0.181	0.571	-0.429	0.432
Self-organization	Request external support	4.776	0.000**	4.805	0.000**	1.597	0.003**
	Legal registry	0.737	0.028*	0.754	0.023*	1.089	0.062

Socio-economic	WUA Size	0.001	0.317	0.001	0.294	-.568	0.292
	WUA Political connections	0.931	0.034*	0.921	0.036**	2.324	0.006**
	WUA Income	0.037	0.774	0.034	0.791	0.040	0.871
Learning	WUA experience	0.062	0.000*	0.064	0.000**	1.011	0.064
	Leader education	0.016	0.618	0.014	0.655	-0.388	0.457
	Leader resides inside community	0.455	0.240	0.453	0.244	0.537	0.422
	Intraclass variance	0.035					
	Likelihood Ratio Test	94.18	0.000**				
	Adjusted R^2			0.53			
	Hosmer and Lemeshow					6.859	0.552

N=102. ** significant 1% or less and * significant 5% or less
(1) In the logit model, the adaptation index and all continues explanatory variables were converted to binary variables to test possible non-linear relations.

The influence of community level characteristics over adaptation is tested with a linear model (using ordinary least squares) and with a logit model to test possible non-linear relations. As shown is table 4 (adjusted R^2 and Hosmer and Lemeshow), both models have relatively good statistical fit.

Water/community relations. Table 4 shows that high perceived water scarcity (significantly in the linear model) and higher perceived changes in water scarcity over the last decades, positively influence the associations' decisions to implement more adaptation strategies. In addition, the negative coefficient of the vertical location variable in the regressions shows that communities in a relatively lower position are more active implementing adaptation strategies. Similar to Lebel et. al (2005), this result (although not statistically significant) suggests that communities in a lower position have to be more active implementing adaptation strategies (such as purchasing upstream land) in order to be able to gain control over the resource and reduce potential conflicts with upstream communities.

Self-organization capacity. As expected, regression results show (significantly) that WUAs that are organized enough to be able to formally request funding external support to local municipalities or NGOs are also able to implement more adaptation strategies. The other variable used as a proxy of self-organization, legal registry, is also positively related (and significantly in the linear model) to adaptation.

Socio-economic capacity. The linear model shows (although not statistically significant) that bigger associations could facilitate adaptation. As in previous research (Poteete and Ostrom, 2004), this result suggest that it is easier for bigger WUAs to obtain internal and external resources to finance the adaptation strategies. However, when testing non-linear relations with the logit model, the WUA size shows a negative relation with adaptation (again not statistically significant). Previous studies also show that bigger communities have difficulty cooperating to manage water resources (Fujiie et al., 2005, Bardhan, 2000, Dayton-Johnson, 2000). The results in Fúquene suggest that WUAs that are too small have difficulty mobilizing internal or external resources to adapt, nevertheless, if they are too big, the WUAs might have problems coordinating internal efforts to cooperate to implement the adaptation strategies.

As expected, table 4 shows that income and political connections (significantly), two important variables that measure the capacity of the WUA to mobilize internal and external financial resources, are positively related to adaptation strategies implementation.

Learning capacity. As expected and similar to previous studies in the Philippines (Fujiie et al., 2005), WUAs in Fúquene that have more years of experience managing their resource and have had more time to learn how to coordinate their internal interests and how to search for external funding are significantly (in the linear model) more likely to implement activities to adapt. The other two variables that try to capture the leader learning capacity, leader education and if he lives inside the community, are not significantly related to the implementation of adaptation strategies.

6 Lessons from adaptation in community-based water management

This study provides a hybrid structural and agency approach to understand adaptation in the context of community-based water management. The analysis show how the broader contextual factors and communities characteristics influence Water User Associations decisions to adapt. The results have important policy implications as they provide insights of how and where government agencies and non-governmental organizations could allocate scarce resources to increase the capacity of local communities to adapt to changing socio-economic conditions and environmental changes such as climate change.

First, the article shows that communities are implementing adaptation strategies to cope with water source degradation. These strategies include adaptations relatively expensive and difficult to implement, such as upstream land purchases for ecosystem protection, infrastructure improvements and changes in pricing rules to conserve the resource. The study shows, that despite some communities capacity to self-organize (autonomously create and modify their own rules, organizational capacity to mobilize resources, etc.), most of them are not self-sufficient. In fact, 50% of the adaptation strategies were implemented with external financial support.

Second, as suggested in other common-pool resource case studies (Marschke and Berkes, 2006), communities in Fúquene are adapting to a combination of structural changes. These contextual factors changes or disturbances include major shocks (climate variability due to El Niño events) and slow changes (deforestation and population increase).

Third, the study finds that the structure or contextual factors influence communities ability to adapt. Although statistical analysis using multi-level models shows that municipal contextual factors are not directly explaining differences in adaptation among the associations, bi-variate analysis shows that contextual factors have indirect effects over adaptation. For example, rainfall patterns in each municipality influences leaders' water scarcity perception, which ultimately facilitates or impede the leader's willingness to implement adaptation strategies. Other factors, such as municipal poverty levels, have indirect effects over WUA's adaptation decisions that are more difficult to assess. Results show that high poverty levels are associated with lower WUA's income and lower leader education, which ultimately influence negatively the ability to adapt. On the other hand, high poverty levels increases the necessity of the WUA to organize in order to request external support from local authorities, which positively influences adaptation. Future research is needed to better understand these indirect effects between contextual factors and the associations characteristics. One statistical approach to fill this gap could be the use of path analysis, although this method would require a much larger sample of municipalities and associations.

Fourth, the results show that community characteristics are also influencing the ability to adapt. The statistical analysis shows that the relation between water resources and communities, and the self-organization, socio-economic and learning capacity are important factors that influence adaptation. One important result, with critical policy implications, is the relation between communities and their local governments. The study shows that self-organized communities are in better shape to bear with relatively high transaction costs to request external support to municipal authorities in order to implement the adaptation strategies. However, municipal investments are not equally distributed among communities, and political connections between communities and local governments are frequently required to receive the support. This imply that communities with low self-organization and socio-economic capacity are isolated from government support, perpetuating their vulnerability to current and future environmental changes. In order to tackle this distribution problems, policies that aim to support communities will have to create mechanisms that recognize the different levels of communities' adaptive capacity and the political relations between communities and their local governments.

Fifth, not all variables were statistically significant as were expected. Future research is needed to find better ways of measuring theoretical concepts such as learning, self-organization, socio-economic capacity.

Finally, it is important to note that this research project focuses on the intention to adapt regardless of the actual success of the adaptation strategies taken by communities. Future research will be needed to 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.

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