Watershed Management and Adaptation to Environmental Change: A Case Study of Water User Associations in the Colombian Andes[1]

Felipe Murtinho

Geography Department

University California Santa Barbara

murtinho@geog.ucsb.edu

ABSTRACT

This study explores how Water User Associations in the rural Andes of Colombia adapt to degradation of their water sources. In the Andean region of South America, understanding local governance is particularly important for water management as many rural communities receive minimal government support 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, due to the absence of outside intervention, autonomous water associations provide water to 41% of the rural population. Despite research on the factors that facilitate collective action in resource management, we have limited knowledge on the specific conditions that enable local communities to adapt to uncertain changing conditions such as land-cover changes, population growth and climate variability. This study explores the factors that determine whether local Water User Associations in the Fúquene watershed in Colombia take measures to manage their micro-watershed in order to adapt to the degradation of their water resources. Fúquene is an ideal place to examine how local communities adapt to water degradation because in most communities access to safe drinking water depends on the management decisions of the user associations and the region faces uncertain water conditions due to land-use, demographic changes and climate variability due to El Niño events.

---

[1] Paper presented in the 2009 Amsterdam Conference on the Human Dimensions of Global Environmental Change 'Earth System Governance: People, Places and the Plant' 2-4 December 2009.
Theme 3: Adaptiveness of Earth System Governance. Panel 4: Water Governance

This article presents an analysis of the micro-watershed management decisions and the characteristics of 111 Water User Associations in 15 municipalities of the Fúquene watershed in Colombia. Specifically the article analyzes: 1) the different adaptation strategies that communities are implementing to adapt to water sources degradation, 2) how the broader contextual factors (environmental and socioeconomic) influence the decisions to adapt, and 3) how the associations' characteristics facilitate (or impede) the implementation of the associations' adaptation strategies. The study uses qualitative and quantitative methods including in-depth interviews to key informants and statistical analysis with information from water user associations' surveys, municipal socio-economic information, 44 years of daily hydro/meteorological data and land-use/land cover maps for 1987 and 2005.

The article results show how and why characteristics at two different levels (the associations' and the broader contextual context) impact the decision of the associations to adapt to changes in water conditions. Research findings show that there are two important factors that facilitates communities ability to adapt: self organization and external support. The results have important policy implications as they suggest that external support will be needed in the context of future changes in water availability due to climate change. However, policies to support communities will have to recognize the different levels of communities' adaptive capacity and that governments usually do not distribute their support equally among communities.

Acknowledgements

This research have not been possible without the support of National Science Foundation, Inter-American Foundation Proyecto Páramo Andino and University California Santa Barbara. I would like to thank the Water User associations leaders for sharing their time and opinions with me; Fundación Humedales, CAR e Instituto Humboldt for their support in Colombia, and specially to Johanna Pisco y Mario Hernández for their incredible help during fieldwork. In addition, many thanks to Tanya Hayes for her comments on earlier drafts.

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 of 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 have begun to examine how resource users address external change (Hayes, 2008, Ostrom, 2008, Richards, 1997, Smit and

Wandel, 2006), we have yet to identify key factors that facilitate adaptation to external change.

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 article will analyze: 1) the different adaptation strategies that communities are implementing to adapt to water source degradation, 2) how the broader contextual factors (environmental and socioeconomic) influence the decisions to adapt, and 3) how the associations' characteristics facilitate (or impede) the implementation of the associations' 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. I chose to study Fúquene because it is representative of political, 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 an analysis of how the broader context and communities characteristics influence adaptation. Understanding the broader context is important because we need to better understand what exactly communities are trying to adapt to (Smit et al., 2000, Murtinho and Hayes, 2008). In many cases, there is not just one factor or disturbance but a combination of different types of contextual factors (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 the disturbances or contextual changes are linked to communities responses. However, understanding the broader context and community responses is not enough to fully understand how communities might cope with external changes. We also need to study the community characteristics since the same socio-economic or environmental context in a region can generate different responses due to communities diversity in their capacity to adapt.

In the following section, I provide 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, I analyze the adaptation strategies that communities are implementing and how the contextual and community level characteristics influence their decisions to adapt.

2 Adaptation in Common-Pool Resource Systems

In order to understand how communities in a decentralized context of water management adapt to water source degradation, this study uses a framework that enables the researcher to understand how structural and institutional factors interact with and influence community decision-making (Ostrom, 1990). 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 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.

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

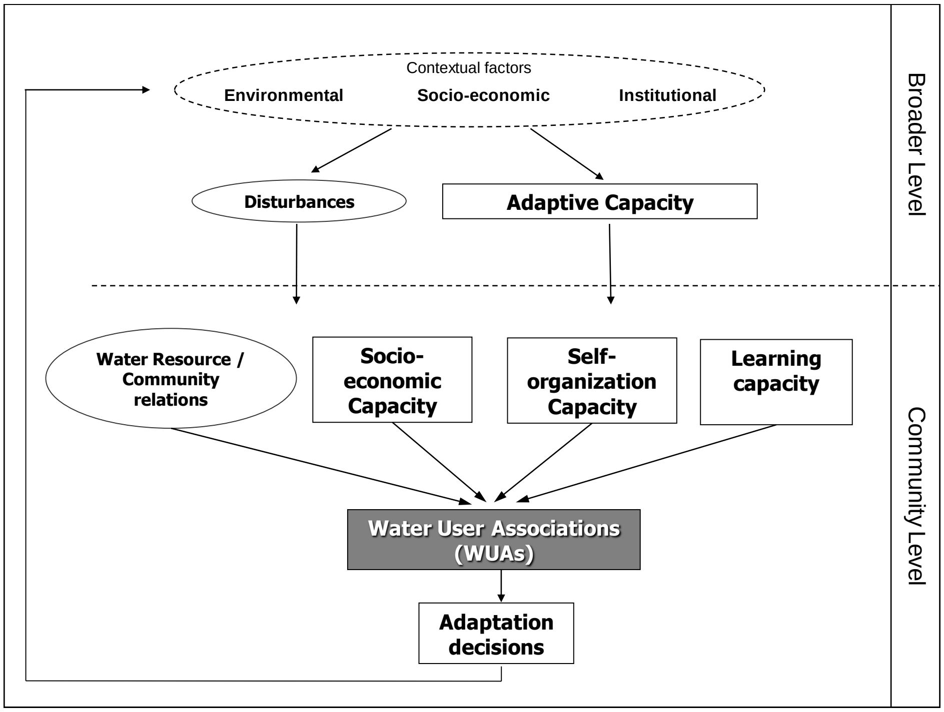
The New Institutional Economics (NIE) literature provides a framework to understand not just individual decisions but also, collective decisions. Given the role of collective decision-making in water management, NIE is particularly useful for this analysis. It emphasizes the analysis of institutional variables and other factors that may contribute to cooperation. Ostrom's use of NIE, for example, focuses on individual and collective behavior, but in addition, it explicitly includes structural political and economical contextual factors that shape human decisions (Ostrom, 2005). With respect to resource management, findings from NIE research identify how particular socio-economic and organizational characteristics facilitate successful governing of local communal resource management (Agrawal, 2001, Bardhan, 2000, Meinzen-Dick et al., 2002, Ostrom, 1990). In recent years, NIE 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 collective action and adaptation has highlighted certain characteristics that influence the collective decision-making and management of common-pool resources like water. These studies reveal the five broad following categories at two levels: broader level and community level (see figure 1):

Figure 1: Conceptual model. Factors that shape adaptation



Contextual factors: At the broader level, 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. 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 shaping their capacity to adapt. For example, a region's socio-economic characteristics and institutional context (i.e. infrastructure, 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).

Resource/community relations: 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 fewer options to adapt, due to higher political and economic costs trying to control water supply due to negotiations with communities in the upper parts of the watershed (Lebel et al., 2005).

Self-Organization capacity: Previous research indicates that the likelihood of collective action increases when communities have previous organizational experience, strong local leadership and when community members can participate in the collective decision processes to create/change their own rules and adaptation strategies (Bebbington et al., 2006, Fujiie et al., 2005, Meinzen-Dick et al., 2002, Ostrom, 1999, White and Runge, 1994).

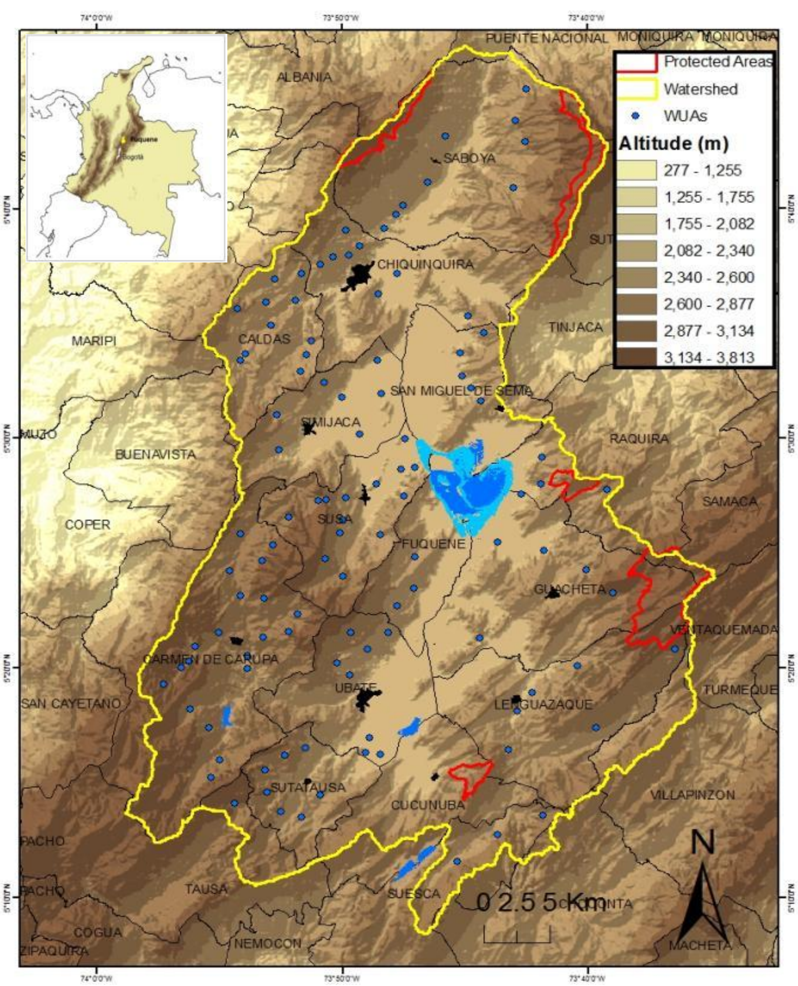
Socio-economic capacity: Researchers argue that smaller communities will be able to build trust relations, cooperate and manage communal natural resources more easily, including water systems (Agrawal, 2001, Bardhan, 2000, Fujiie et al., 2005, Meinzen-Dick et al., 2002). However, if communities are too small it will be difficult to mobilize internal or external financial resources in order to adapt (Poteete and Ostrom, 2004). Other important socio-economic factors include: social networks among communities and with authorities, and income and wealth levels. These factors allow communities 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).

<u>Learning capacity</u>: Adaptation also arises when communities have had an opportunity 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 is 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 summer (32% of total annual rainfall). It is important to note, that 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. Due to this high rainfall difference between seasons, local communities perceive high water scarcity levels in the northern part of the watershed (Murtinho, 2009).

El Niño 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, still remembered by local communities (Murtinho, 2009). However, research in Fúquene shows that there is no statistically significant trends in the last 44 years in rainfall, its distribution along the year, or the frequency of dry events (despite local leaders perceptions) (Murtinho, 2009). Nevertheless, global climate change may further increase the rainfall variability in the Andes of Colombia. According to global climate models from the Fourth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC), rainfall in this region could increase by about 5% for December, January and February and during June, July and August it could decrease by 5% (Christensen et al., 2007).

In 2005, only 16,9% of the Fúquene territory was covered by natural and semi-natural ecosystems (including strategic water regulators such as páramos and forests) (Buytaert et al., 2006, Harden, 2006). 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). Between 1987 and 2005, the watershed has lost 23.3% of these ecosystems.. Most of this area was replaced with agriculture, pasture and mining systems (CAR, 2006, Murtinho, 2009).

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 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 grow (3% average annual growth), rural population increased until the 90s 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 threatening ecosystems loss, growing population density also can lead to increasing water demand.

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 the WUAs 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).

In Colombia, several governmental agencies, operating at different jurisdictional scales, are responsible for water conservation. 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 control and sanctioning of 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. In addition, they have to invest in rural development, including investing in water management infrastructure (watershed protection, water tanks, distribution networks, etc.). In Fúquene, rural investment levels varies among municipalities, from a 5-year average of US$30 per person in the northern part of the watershed, to more than US$100 per person in other regions (DNP, 2008).

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, the information gathered on the adaptation strategies implemented by WUAs is cross-sectional data. 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).

In order to analyze the factors that influence the 11 identified adaptation strategies, I aggregate them using an index[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 analysis of the factors that shape collective decisions to adapt is divided in two levels: contextual factors and adaptation at the municipal level, and WUAs characteristics and adaptation at the community level.

[3] 17 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)

4.1 Contextual Factors: Municipal Level Analysis

As mentioned, contextual factors can affect the WUAs initiative to adapt in two ways: (1) as the disturbances that WUAs respond to, and (2), as factors that influence WUAs adaptive capacity. In the case of Fúquene, the disturbances are environmental and socio-economic changes. This study does not include institutional contextual factors. Since all the municipalities are located under the same regional government jurisdiction, there is no clear variation among regulations that could influence adaptation decisions. For this analysis, I included as socio-economic and environmental disturbances: municipal land cover change (loss of natural and semi-natural ecosystems) and municipal rural population change (as a proxy of water demand changes). There are no increasing or decreasing trends in Fúquene's total rainfall, distribution or frequency of dry events, so long-term trend variables were not included. In order to assess the impacts of El Niño events, distribution of rainfall along the year (January and summer fraction of total annual rainfall) is included as an environmental disturbance. Second, the socio-economic current context influences WUAs capacity to adapt. This includes: municipal population density in 2005, rural poverty (% of households with unsatisfied needs), and 5-year average municipal investments in rural water management in absolute terms and adjusted by rural population to obtain the investment per capita.

To measure the relations between these contextual factors and the municipal average of the WUAs adaptation index, I used the Spearman Rho coefficient to test possible non-linear bivariate correlations. Since the sample is very small (12 to 14 municipalities[5]), results were double checked with scatter plots for better interpretation (not shown in this article).

4.2 Water User Association characteristics: Community Level Analysis

For the WUA level analysis, I use linear regression analysis where the dependant variable is the WUA adaptation index score and the explanatory variables are based on the conceptual model explained in section 2.1, as in the following general equation:

[5] From the 16 municipalities in Fúquene, one does not have WUAs. In addition, in order to avoid biases in the analysis, one municipality is excluded since only has one WUA. For correlations using municipal socio-economic data, two additional municipalities had to be excluded since just a small part of these municipalities is located inside the watershed.

Equation 1: *Adaptation Index = f (community/resource relation, self-organization capacity, socio-economic capacity, learning capacity)*

In order to choose the final model (see equation 2), I selected variables that could be important to explain the initiative to adapt based in the results of semi-structured interviews to key informants; 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); results from bivariate statistical analysis; and that the model had a relatively high adjusted R^2. In addition, I checked that the model satisfied the statistical assumptions of linear regressions[6].

The variables used in the analysis were calculated from the WUA leader survey. Categorical variables (i.e. perceived water scarcity) were later converted to binary variables in order to be used in the regression analysis. The following linear equation represents the final selected model:

Equation 2: *Adaptation* = $\beta_0 + \beta_0$**water scarcity* + β_0** source inside* + β_0**water scarcity change* + β_0**experience* + β_0** request support* + β_0**registry* + β_0**size* + β_0**political connections* + β_0**income* + β_0**education* + β_0**residency* + ε

Where *Adaptation* is the dependent variable measured by an index score, β_i are the parameters to be estimated, and ε is the error term. The explanatory variables included in the model are grouped based on equation 1 and defined as follows:

Water/community relations: perceived *water scarcity* in the summer season (measured in a scale of 1 to 5); water *source inside* the community (a variable that tries to measure the relative location of the community inside the watershed. If the water source is outside the community, the water source has to be located in an upstream community). And finally, perceived *water scarcity* change relative to 20 or 30 years ago (measured in a scale of 1 to 5) .

Self-organization capacity variables: association *experience* (measured as the number of years the association has been distributing water); *request external support* (percentage of the adaptation strategies that the WUA officially requested support from the

[6] I checked normality of residuals, heteroscedasticity and autocorrelation of the residuals. In addition, I checked possible endogeneity problems (specially for water scarcity, water scarcity change and request external support)

government or NGOs); and legal *registry* (measures if the WUA is registered to be legally recognized as a community based organization).

Socio-economic capacity variables: *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).

And finally, learning capacity variables: leader *education* (number of years of formal education), and the *residency* location of the leader (inside or outside the community).

5 Results

5.1 Adaptation strategies

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

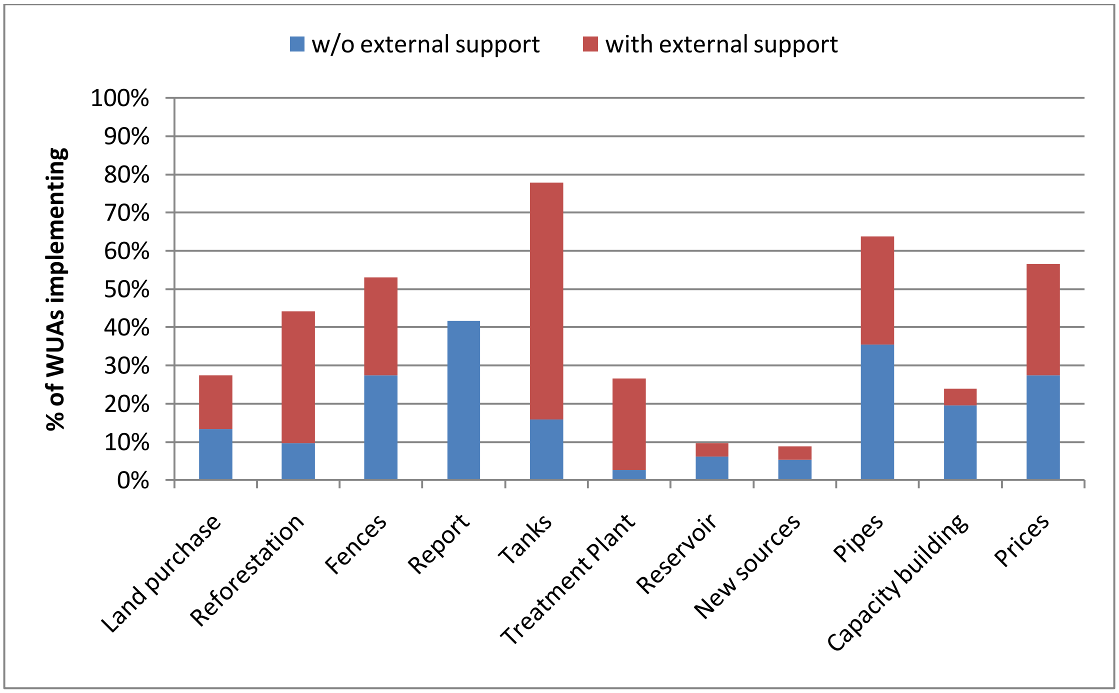
Micro-watershed management. The purpose of these strategies is to conserve and restore native ecosystems (páramos and forests) close to the water sources with the goal of protecting the water resource (in terms of quality and quantity). To do this, WUAs purchase upstream land to create informal protected 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[7]: 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 are water storage tanks (almost 80% of WUAs). Reservoirs and alternative water sources are

[7] 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).

the least used adaptation strategies. This reflects the high costs and lack of alternative sources already in use by neighbor communities

Figure 3. Percentage of WUAs implementing adaptation strategies



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.

5.2 Contextual Factors and Adaptation

Contextual factors can affect the WUAs initiative to adapt in two ways: (1) as the disturbances that WUAs respond to, and (2), as factors that influence WUAs adaptive capacity. Table 1 presents the results of the correlations between the different contextual factors (measured at the municipal level) and the average adaptation index score for each municipality. Looking at scatter plots between the contextual factors and the adaptation index, there are clear correlations. However, due to outliers and a small sample there are no statistically significant correlations (see table 1).

Table 1. Bivariate Correlations with Adaptation Index (municipal average score)

Variable		N	Coefficient	p-value
Disturbances	Land Cover Change	14	-0.235	0.418
	Rural Population Change	12	0.145	0.670
	Fraction Summer Rainfall	14	-0.196	0.503
	Fraction Summer (January) Rainfall	14	-0.354	0.215
Influence adaptive capacity	Rural Population Density	12	0.070	0.829
	Rural Poverty	12	-0.084	0.795
	Rural Water Investment	12	0.042	0.897
	Rural Water Investment per capita	12	0.140	0.665

First, in terms of the disturbances that WUAs adapt to, results suggest that municipalities that have high rates of deforestation and population growth, and are located where rainfall distribution is less homogeneous during the year (where leaders perceive higher water scarcity and have experienced water scarcity crisis "events"), also have communities that are implementing more adaptation strategies. This shows that communities are responding to the broader environmental and socio-economic changes in their territories.

Second, results suggest that contextual factors influence adaptation by increasing or increasing the WUAs adaptive capacity. Municipalities with higher population density, which could imply relatively higher water demand in the same area, also tend to implement more strategies. Furthermore, municipalities that invest more in rural projects in water management (total or per capita) appears to increase the number of strategies. This is also expected, since almost half of the WUAs adaptation strategies are supported by municipal governments. Finally, municipalities with a higher proportion of poor people tend to implement less adaptation strategies. This relation could be explained due to the significant correlation between relatively poor municipalities and relatively low water management per capita investment.

5.3 Water User Association's Characteristics and Adaptation

In Fúquene watershed there is great diversity in terms of how WUAs relate to water resources, and their self-organization, socio-economic and learning capacity. A summary of these characteristics is presented in table 2. In addition, table 3, shows the results of the regression model that determines how these characteristics influence the number of adaptation strategies implemented by the water associations.

Table 2. Water User Associations (WUAs) characteristics

Variable		Description	Mean	Std D.	Min.	Max.
	Adaptation Index	Score	0.01	1.99	-3.50	5.79
Water / community relations	Perceived water scarcity	1=medium to very high	0.52	0.50	0.00	1.00
	Water source inside community	1=inside	0.68	0.47	0.00	1.00
	Perceived water scarcity change	1=higher	0.63	0.49	0.00	1.00
Self-organization	Association experience	Years	16.92	9.55	0.10	43.00
	Request external support	%	33.43	19.48	0.00	70.00
	Legal registry	1=yes	0.65	0.48	0.00	1.00
Socio-economic	Size	# users	126.14	121.87	12.00	575.0
	Political connections	%	60.90	36.36	0.00	100.0
	Income	US$/month	1.19	1.11	0.00	6.37
Learning	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

Water/community relations. Currently, 51% of WUAs perceive that there are medium, high or very high water scarcity problems in the summer. Even in the wet months, 9% of WUAs cannot distribute water to their users every day. This problem gets worse when 41% of the associations cannot distribute water every day. According to 63% of WUAs, currently there is higher water scarcity than previous decades. Table 3 shows that perceived high water scarcity (significantly) and higher water scarcity changes in the last decades, influence positively the associations decisions to implement more adaptation strategies.

In Fúquene, in 32% of the cases, the WUA water source is outside their own community. If the water source is outside the community, the water source has to be located in an upstream community (so the WUA is relatively in a lower position in the watershed). Contrary to Lebel et al. (2005) suggestions, the negative coefficient of this variable (although not statistically significant) shows that communities with water sources outside their jurisdiction are not thwarted to implement strategies to adapt.

Table 3: Regression model results. Dependant variable: Adaptation Index (score)

Variable		**Coefficient**	**p-value**	
	Intercept	-4.735	0.000	**
Water/community relations	Perceived water scarcity	0.589	0.048	*
	Water source inside community	-0.181	0.571	
	Perceived water scarcity change	0.151	0.619	
Self-organization	Association experience	0.064	0.000	**
	Request external support	4.805	0.000	**
	Legal registry	0.754	0.023	*
Socio-economic	Size	0.001	0.294	
	Political connections	0.921	0.036	**
	Income	0.034	0.791	
Learning	Leader education	0.014	0.655	
	Leader resides inside community	0.453	0.244	

Adjusted R^2: 0.53 N=102. ** significant 1% or less and * significant 5% or less

<u>Self-organization capacity</u>. WUAs have been distributing water on average for 17 years and the oldest association was created in 1965. Similar to previous studies in the Philippines (Fujiie et al., 2005), WUAs in Fúquene that have more years of experience managing their resource are significantly more likely to implement activities to adapt.

One third of the WUAs (35%) are not registered in order to have legal recognition as a community organization. In addition, there are great differences in the number of projects submitted to request external support. On average, WUAs ask for four of the eleven possible adaptation strategies, however in 7% of the cases WUAs did not requested funds at all.

Self-organized WUAs are more likely to be able to fulfill legal requirements and submit projects to request external support from the local or state government, which also facilitates (as seen in table 3) the chances of implementing the adaptation strategies. Some WUA leaders do not have the knowledge or financial resources to spend time fulfilling legal requirements and submitting projects. However, in some well-organized WUAs, leaders seek for external help (neighbor leaders or community members) to bear with these relatively high transaction costs (pers comm, WUA leaders 2008).

Socio-economic capacity. Size of the associations varies from 12 up to 575 users, with an average of 126 users per association. Results in Fúquene show (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.

WUAs' main income source is households' water consumption fees. On average and taking into account that not all users pay on time and that WUAs have different price systems, the associations collect US$1.19 a month per user. The WUA with the highest income collects US$6.37 a month per user. Table 3 shows that income is positively related to adaptation strategies implementation, although not statistically significant.

There are substantial differences in the level of political connections between the WUAs and local authorities. In 19% of the cases, WUAs did not have any success getting external support, while 30% got all the requested resources. It is important to mention, that receiving all the requested resources does not imply that 100% of the project costs are covered. Usually the government helps with funding materials and the WUA provides the rest of the costs and community labor. As shown in Table 3, political connections is the only socio-economic capacity variable that is positively and statistically significant. 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 reported 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 stated that they requested external funds to local authorities, but they did not want to establish direct contact with them. They stated 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).

Learning capacity. Most of the associations have not received water management training (or informal education) form the government, and none of them have had any training from nongovernmental organizations (NGOs). WUA leaders have in average 8 years of formal education. However, half of them just have elementary school (5 years or less), while 25% have started or finished higher education. Some of the leaders reside outside the watershed or in urban areas, but most of them (83%) reside inside their community (which could facilitate learning by experience the changes in the water resource, the problems and possible solutions). As expected, these variables that try to measure learning capacity are positively related to the implementation of adaptation strategies, although not significantly.

6 Discussion

Results show how Water User Associations in the Fúquene watershed in Colombia are implementing strategies to manage their water resources and their micro-watersheds. These strategies include adaptations relatively expensive and difficult to implement, such as upstream land purchases for ecosystem protection, infrastructure improvement and changes in pricing rules to conserve the resource.

If we want to better understand these adaptation processes, we first need to identify what exactly are communities adapting to (Smit et al., 2000). 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. Furthermore, the interviews are supported with the results of the regression analysis presented in table 3. This analysis show that if Association's leader perceive higher current water scarcity levels, the WUA respond to this scarcity with adaptation strategies.

As suggested in other common-pool resource case studies (Marschke and Berkes, 2006), communities in Fúquene are adapting to a combination of contextual factors. These contextual factors or disturbances include slow changes (deforestation and population increase) and major shocks (climate variability due to El Niño events). Slow changes, such as loss of natural and semi natural ecosystems are significantly related to the inability of WUAs to distribute water every day during the summer season and the perception of water scarcity (Murtinho, 2009). In fact, 40% of leaders stated that deforestation is the cause of increased water scarcity. However, as shown in table 1, when the loss of ecosystems is compared directly to the adaptation levels there is not a significant relation. The other slow change in Fúquene is population increase. The direct effect of population increase (increase in water demand) over adaptation is positively related, but not statistically significant. Indeed, just 7% of the leaders perceived this as the cause of increasing water scarcity. However, population increase could have an indirect influence over adaptation, since it has a significant relation with land cover change (Murtinho, 2009). The second type of changes, major shocks, also appear to have an influence over WUAs adaptation decisions (27% of the leaders think that increased water scarcity is due to rainfall changes). As shown in section 5.2, municipalities where El Niño events are perceived to have higher impact, are the regions where there are higher levels of adaptation (although this relation is not statistically significant).

In response to the question of what conditions facilitate adaptation, results in Fúquene suggest that self-organization capacity is a key factor that facilitates adaptation. This results is similar to previous research on water management and collective action (Fujiie et al., 2005, Meinzen-Dick et al., 2002, Ostrom, 1999, White and Runge, 1994). Table 3 shows that the three variables used to quantify self-organization (association experience, request of external support and legal registry) are positively and significantly related to adaptation.

The second key factor that influences adaptation is external support. Although, 50% of the adaptation strategies were implemented without external support (from government or NGOs) (see figure 3), the role of local government is very important as a source of infrastructure investment. As shown in table 1, municipal investment is positively related to adaptation, although not statistically significant. This result is not surprising since the municipal investments are not equally distributed among communities. Not all WUAs are well organized enough to bear relatively high transaction costs (i.e. legal requirements to submit projects) in order to request external support. Furthermore, in some cases, requesting external support is not enough to receive funds, so political connections between WUAs and local governments are required to make these requests effective.

Finally, results suggest the need of future research to better understand some of the factors that influence adaptation. These factors include economic and learning capacity and the relative location of the WUA in the watershed. For instance, most of the economic capacity variables were not statistically significant. These variables include WUA size and income, which might positively influence adaptation, and the level of poverty in the municipality, which might negatively influence WUAs adaptation capacity. In the same way, the relative location of the WUA in the watershed (upstream or downstream) and the learning capacity influences adaptation, but the variables available for the analysis are not statistically significant.

7 Conclusion

This study provides an analysis of how the broader context and communities characteristics influence adaptation in a decentralized water management context. 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 environmental and socio-economic conditions.

First, the article shows that communities are implementing adaptation strategies to cope with water source degradation due to environmental and socio-economic changes. These changes or disturbances include slow changes (deforestation and population increase) and major shocks (climate variability due to El Niño events).

Second, the study finds that there are two important factors that facilitates communities ability to adapt: self organization and external support. The statistical analysis show that organized communities are better able to find resources and implement adaptation strategies (including watershed protection, infrastructure improvements, and rules to conserve the resource). Self-organized communities are also in better shape to bear with relatively high transaction costs to request external support to implement the adaptation strategies. The study in Fúquene shows that external support, such as municipal water investment, influences communities ability to adapt. However, municipal investments are not equally distributed among communities, and political connections between communities and local governments are frequently required to receive the support.

These results show that communities can and have adapted to environmental changes, although in most cases, they have not been self-sufficient. This suggest that external support will be needed in the context of future changes in water availability due to climate change. However, policies 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.

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, changes in livelihoods, distribution of costs and benefits and economic efficiency.

8 References

AGRAWAL, A. 2001. Common property institutions and sustainable governance of resources. *World Development,* 29**,** 1649-1672.

BARDHAN, P. 2000. Irrigation and cooperation: An empirical analysis of 48 irrigation communities in South India. *Economic Development and Cultural Change,* 48**,** 847-865.

BATTERBURY, S. & FORSYTH, T. 1999. Fighting back: Human adaptations in marginal environments. *Environment,* 41**,** 6.

BEBBINGTON, A., DHARMAWAN, L., FAHMI, E. & GUGGENHEIM, S. 2006. Local capacity, village governance, and the political economy of rural development in Indonesia. *World Development,* 34**,** 1958-1976.

BERKES, F., COLDING, J. & FOLKE, C. 2003. *Navigating social-ecological systems: building resilience for complexity and change,* Cambridge, UK, Cambridge University Press.

BERKES, F. & TURNER, N. J. 2006. Knowledge, learning and the evolution of conservation practice for social-ecological system resilience. *Human Ecology,* 34**,** 479-494.

BURTON, I., KATES, R. W. & WHITE, G. F. 1993. *The environment as hazard,* New York, The Guilford Press.

BUYTAERT, W., CELLERI, R., DE BIEVRE, B., CISNEROS, F., WYSEURE, G., DECKERS, J. & HOFSTEDE, R. 2006. Human impact on the hydrology of the Andean paramos. *Earth-Science Reviews,* 79**,** 53-72.

CAR 2006. Plan de Ordenamiento de la Cuenca de los Ríos Ubaté y Suárez. Corporación Autónoma Regional de Cundinamarca - CAR.

CAR 2008. Información Hidrometereológica. Corporación Autónoma Regional de Cundinamarca.

CARPENTER, S., WALKER, B., ANDERIES, J. M. & ABEL, N. 2001. From metaphor to measurement: Resilience of what to what? *Ecosystems,* 4**,** 765-781.

CARR, D. L., MURTINHO, F., PAN, W., BARBIERI, A., BILSBORROW, R., SUCHINDRAN, C. & WHITMORE, T. 2008. Un análisis multi-nivel de población y deforestación en El Parque Nacional Sierra de Lacandón, Petén, Guatemala. *Documents D'Análisi Geográfica,* 52**,** 49-67.

CHOWDHURY, R. R. & TURNER, B. L. 2006. Reconciling agency and structure in empirical analysis: Smallholder land use in the southern Yucatan, Mexico. *Annals of the Association of American Geographers,* 96**,** 302-322.

CHRISTENSEN, J. H., HEWITSON, B., BUSUIOC, A., CHEN, A., GAO, X., HELD, I., JONES, R., KOLLI, R. K., KWON, W. T., LAPRISE, R., MAGAÑA RUEDA, V., MEARNS, L., MENÉNDEZ, C. G., RÄISÄNEN, J., RINKE, A., SARR, A. & WHETTON, P. 2007. Regional Climate Projections. *In:* SOLOMON, S., QIN, D., MANNING, M., CHEN, Z., MARQUIS, M., AVERYT, K. B., TIGNOR, M. & MILLER, H. L. (eds.) *Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change.* Cambridge, United Kingdom and New York, NY, USA: Cambridge University Press.

COLMENARES, R. & MIRA, J. C. 2007. Paradojas del agua en Colombia. Privatización y alternativas públicas. *In:* CORREA, H. D. (ed.) *Colombia: ¿Un futuro sin agua?* Bogota: Ecofondo, Foro Nacional Ambiental y Ediciones desde Abajo.

COULTHARD, S. 2006. Adaptation and survival, or conflict and division: different reactions to a changing common property resource institution in a south Indian fishery. *"Survival of the Commons: Mounting Challenges and New Realities," the Eleventh Conference of the International Association for the Study of Common Property.* Bali, Indonesia: International Association for the Study of Common Property.

DANE 2005. Censo General 2005. Departamento Administrativo Nacional de Estadistica.

DAYTON-JOHNSON, J. 2000. Determinants of collective action on the local commons: a model with evidence from Mexico. *Journal of Development Economics,* 62**,** 181-208.

DNP 2008. Informes Presupuestales. Departamento Nacional de Planeacion.

EAKIN, H. 2005. Institutional change, climate risk, and rural vulnerability: Cases from central Mexico. *World Development,* 33**,** 1923-1938.

EAKIN, H. & LEMOS, M. C. 2006. Adaptation and the state: Latin America and the challenge of capacity-building under globalization. *Global Environmental Change-Human and Policy Dimensions,* 16**,** 7-18.

EAKIN, H. C. 2006. *Weathering risk in rural Mexico: climatic, institutional, and economic change,* Tucson, University of Arizona Press.

FOLKE, C., HAHN, T., OLSSON, P. & NORBERG, J. 2005. Adaptive governance of social-ecological systems. *Annual Review of Environment and Resources,* 30**,** 441-473.

FORD, J., PEARCE, T., SMIT, B., WANDEL, J., ALLURUT, M., SHAPPA, K., ITTUSUJURAT, H. & QRUNNUT, K. 2007. Reducing vulnerability to climate change in the Arctic: The case of Nunavut, Canada. *Arctic,* 60**,** 150-166.

FUJIIE, M., HAYAMI, Y. & KIKUCHI, M. 2005. The conditions of collective action for local commons management: the case of irrigation in the Philippines. *Agricultural Economics,* 33**,** 179-189.

GAUTAM, A. & SHIVAKOTI, G. 2004. Evolution and impacts of community based forest management in the hills of Nepal. *"The Commons in an Age of Global Transition: Challenges, Risks and Opportunities," the Tenth Conference of the International Association for the Study of Common Property.* Oaxaca, Mexico: International Association for the Study of Common Property.

GIBSON, C. C. & BECKER, C. D. 2000. A lack of institutional demand: why a strong local community in western Ecuador fails to protect its forest. *In:* GIBSON, C. C., MCKEAN, M. A. & OSTROM, E. (eds.) *People and forests : communities, institutions, and governance.* Cambridge, Mass.: MIT Press.

GROTHMANN, T. & PATT, A. 2005. Adaptive capacity and human cognition: The process of individual adaptation to climate change. *Global Environmental Change-Human and Policy Dimensions*, 15**,** 199-213.

HARDEN, C. P. 2006. Human impacts on headwater fluvial systems in the northern and central Andes. *Geomorphology,* 79**,** 249-263.

HAYES, T. M. 2008. The robustness of indigenous common-property systems to frontier expansion: Institutional interplay in the Mosquitia Forest Corridor. *Conservation and Society*, 6**,** 117-129.

IAVH. 2007. *Mapa Ecosistemas (1987 - 2005),* 1:100.000. Bogota: Instituto Alexander von Humboldt.

IDEAM 2002. Efectos naturales y socioeconómicos del fenómeno El Niño en Colombia. Instituto de Hidrología, Metereología y Estudios Ambientales - IDEAM.

IVEY, J. L., SMITHERS, J., DE LOE, R. C. & KREUTZWISER, R. D. 2004. Community capacity for adaptation to climate-induced water shortages: Linking institutional complexity and local actors. *Environmental Management,* 33**,** 36-47.

JANSSEN, M. A., ANDERIES, J. M. & OSTROM, E. 2007. Robustness of social-ecological systems to spatial and temporal variability. *Society & Natural Resources,* 20**,** 307-322.

JANSSEN, M. A. & OSTROM, E. 2006. Resilience, vulnerability, and adaptation: A cross-cutting theme of international human dimensions programme on global environmental change. *Global Environmental Change-Human and Policy Dimensions,* 16**,** 237-239.

LEBEL, L., ANDERIES, J. M., CAMPBELL, B., FOLKE, C., HATFIELD-DODDS, S., HUGHES, T. P. & WILSON, J. 2006. Governance and the capacity to manage resilience in regional social-ecological systems. *Ecology and Society,* 11.

LEBEL, L., GARDEN, P. & IMAMURA, M. 2005. The politics of scale, position, and place in the governance of water resources in the Mekong region. *Ecology and Society,* 10.

MARSCHKE, M. J. & BERKES, F. 2006. Exploring strategies that build livelihood resilience: a case from Cambodia. *Ecology and Society,* 11**,** 16.

MEINZEN-DICK, R., RAJU, K. V. & GULATI, A. 2002. What affects organization and collective action for managing resources? Evidence from canal irrigation systems in India. *World Development,* 30**,** 649-666.

MURTINHO, F. Year. Contrasting climate and land use changes with local perceptions: a case study of water management adaptation in the Andes of Colombia. *In:* AWRA Annual Conference, November 9-12 2009 Seattle. American Water Resources Association - AWRA.

MURTINHO, F. & HAYES, T. M. 2008. Insights from the field for measuring and analyzing adaptation in common-pool resource management. *Biennial Conference of the International Association for the Study of the Commons.* Cheltenham, England.

NELSON, D., ADGER, W. N. & BROWN, K. 2007. Adaptation to environmental change: contributions of a resilience framework. *Annual Review of Environment and Resources,* 32**,** 395-419.

OLSSON, P. & FOLKE, C. 2001. Local ecological knowledge and institutional dynamics for ecosystem management: A study of Lake Racken Watershed, Sweden. *Ecosystems,* 4**,** 85-104.

ORTIZ, N., MORALES, M., BERNAL, N. R., RODRÍGUEZ, N., BAPTISTE, M. P. & FRANCO, A. M. 2005. *Línea base de la biodiversidad en la jurisdicción de la Corporación Autónoma Regional de Cundinamarca - CAR,* Bogotá, D.C., Instituto de Investigacion de Recursos Biológicos Alexander von Humboldt y Corporación Autónoma Regional de Cundinamarca - CAR.

OSTROM, E. 1990. *Governing the commons: the evolution of institutions for collective action,* Cambridge, Cambridge University Press.

OSTROM, E. 1999. Coping with tragedies of the commons. *Annual Review of Political Science,* 2**,** 493-535.

OSTROM, E. 2005. *Understanding institutional diversity,* Princeton, Princeton University Press.

OSTROM, E. 2008. How do institutions for collective action evolve? *Annual Neale Wheeler Watson Lecture.* Nobel Museum, Stockholm, Sweden.

PEÑA, D., REYES, J. & GARCÍA, J. 2007. Un caso de acueductos comunitarios: El Tunjuelo, Bogotá. *In:* CORREA, H. D. (ed.) *Colombia: ¿Un futuro sin agua?* Bogota: Ecofondo, Foro Nacional Ambiental y Ediciones desde Abajo.

PERREAULT, T. 2005. State restructuring and the scale politics of rural water governance in Bolivia. *Environment and Planning A,* 37**,** 263-284.

POTEETE, A. & OSTROM, E. 2004. Heterogeneity, group size and collective action: the role of institutions in forest management. *Development and Change,* 35**,** 435-461.

PRETTY, J. & WARD, H. 2001. Social capital and the environment. *World Development,* 29**,** 209-227.

RICHARDS, M. 1997. Common property resource institutions and forest management in Latin America. *Development and Change,* 28**,** 95-117.

SCHLAGER, E. 2002. Rationality, Cooperation, and Common Pool Resources. *American Behavioral Scientist,* 45**,** 801-819.

SMIT, B., BURTON, I., KLEIN, R. J. T. & WANDEL, J. 2000. An anatomy of adaptation to climate change and variability. *Climatic Change,* 45**,** 223-251.

SMIT, B. & PILIFOSOVA, O. 2001. Adaptation to climate change in the context of sustainable development and equity. *In:* IPCC (ed.) *Climate change 2001: impacts, adaptation and vulnerability.* Cambridge, UK: Cambridge University Press.

SMIT, B. & WANDEL, J. 2006. Adaptation, adaptive capacity and vulnerability. *Global Environmental Change-Human and Policy Dimensions,* 16**,** 282-292.

USAID & MAVDT 2005. Lineamientos de política de agua potable y sanemaiento básico para la zona rural de Colombia. Ministerio de Ambiente, Vivienda y Desarrollo Territorial - MAVDT.

VASQUEZ-LEÓN, M. & LIVERMAN, D. M. 2004. The political ecologyof land-use change: affluent ranchers and destitute farmers in the Mexican Municipio of Alamos. *Human Organization,* 63**,** 21.

WHITE, T. A. & RUNGE, C. F. 1994. Common property and collective action - Lessons from cooperative watershed management in Haiti. *Economic Development and Cultural Change,* 43**,** 1-41.