Adaptive capacity, drought and the performance of community-based drinking water organizations in Costa Rica

Róger Madrigal-Ballestero and María A. Naranjo

ABSTRACT

Community-based drinking water organizations (CBDWOs) are the most important providers of water in rural areas of the developing world. They are responsible for coping with future threats due to climate change, besides other non-climatic drivers of change such as demographic growth. The inherent capacities of CBDWOs to adapt to external drivers of change would be greatly conditioned by their capacities to initiate and catalyze collective processes. The rich background of CDBWOs' actual and historical responses to drought phenomena is an essential starting point for understanding both the processes and the limitations of adapting to future adverse climatic events. In this study, we contrast six CBDWOs located in the Costa Rican dry corridor, in order to analyze their ability to self-organize coping with recent annual periodical droughts. We found that CBDWOs implement hard, soft, and ecosystem-based adaptation measures. The decisions in this regard are reactive, tend to follow a sequential order, and are context dependent. One of the main factors that facilitates capital-intensive adaptation measures is the ability of CBDWOs to mobilize internal or external financial resources, which further depends on social capital and the governance structure.

Key words | adaptation, common-pool resources, community-based adaptation governance

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INTRODUCTION

Access to safe drinking water and sanitation is a global concern for meeting the Millennium Development Goals, and in recent years it has been increasingly addressed as a basic human right (UNGA 2010). However, climate change impacts threaten actual and future achievements regarding this issue. Droughts are expected to be more intense and prolonged in different areas of Latin American and the Caribbean (LAC), with significant impacts on the volume, timing, and water quality provided by water suppliers (Kundzewicz *et al.* 2008).

Community-based drinking water organizations (CBDWOs) are the most important providers of water in rural areas of LAC, and play a key role in decentralization and democratization processes in different countries (AVINA 2011). They are responsible for coping with future threats due to climate change, aside from non-climatic drivers of change (e.g., demographic growth). Nearly 1,500 CBDWOs manage piped-water infrastructure, serving around one million people in rural and peri-urban areas of Costa Rica, in many cases operating in isolation from governmental support and supervision (AVINA 2011; Madrigal *et al.* 2011). Despite great disparities in their performance, most CBDWOs are characterized by structural problems such as poor full-cost recovery practices, deficient organizational practices, and malfunctioning infrastructure (ICAA *et al.* 2002; Madrigal *et al.* 2011).

CBDWOs are small groups of people, usually appointed by local villagers, dealing with different collective action problems related to drinking water provision in their communities. Therefore, their inherent capacities for adapting to external drivers of change would be greatly influenced by their capacities to initiate and catalyze collective processes in the communities they represent. Over their lifetime most CBDWOs have taken decisions amidst

doi: 10.2166/wcc.2015.154

fluctuating, seasonal, and scarce water sources, further stressed by socio-economic change. The rich background of CBDWOs' actual and historical responses to drought phenomena is an essential starting point for understanding both the processes and the limitations for adapting to future adverse climatic events. The complex nature of collective adaptation processes involves the identification and analysis of relationships among different actors in the communities, the governance structure in which they interact, the physical and natural resource base on which they depend, and the social, economic, demographic, and political setting in which they reside (Ostrom 2007, 2009).

In this study, we contrast six CBDWOs located in the Costa Rican dry corridor to analyze the different factors and processes that have facilitated their ability to self-organize for coping with recent seasonal droughts. Given that all sampled CBDWOs face a fairly similar level of exposure to droughts (also sharing similarities in size, age of infrastructure, and socio-economic indicators), those CBDWOs that perform better tend to show lower sensitivity to climatic impacts, and hence show a higher adaptive capacity. The determinants of performance in this context give us indirect insight into the conditions that affect adaptive capacity and vulnerability of CBDWOs.

Specifically, the aim of this research is to identify factors that influence the performance of CBDWOs in the context of seasonal droughts; also, it enumerates the adaptation measures implemented by CBDWOs for dealing with droughts and analyzes the conditions facilitating (or preventing) their implementation. We believe this research will help fill the knowledge gap concerning factors affecting CBDWOs' ability to succeed (Madrigal *et al.* 2011) and their implementation of adaptation measures (Murtinho & Hayes 2011). Furthermore, given the spatially and socially differentiated expected impacts of climate change on resource-dependent communities and the context-dependent nature of their adaptive capacity (Adger 2003), we provide insights into the governance structure, actors, and bio-physical setting affecting local adaptation processes. The in-depth analysis of the governance attributes of CBDWOs in the face of climate change is especially critical since these aspects are considered central to understanding the adaptive capacity of human populations (Engle & Lemos 2010).

THEORETICAL BACKGROUND

The Intergovernmental Panel on Climate Change characterizes vulnerability (i.e., susceptibility to harm) to climate change through three concepts: exposure (i.e., the extent to which a system is exposed to any stimuli); sensitivity (i.e., how affected a system is after being exposed to a disturbance); and adaptive capacity (i.e., the system's ability to prepare for and adjust to the climatic stimuli in order to alleviate adverse impacts or to take advantage of new opportunities) (Adger 2006; Engle 2011). Within this framework, adaptive capacity affects vulnerability by modulating exposure and sensitivity (Adger *et al.* 2007; Wolf *et al.* 2010). Adaptation measures are manifestations of adaptive capacity and represent ways of reducing vulnerability (Smit & Wandel 2006). Nevertheless, the latent nature of adaptive capacity prevents us from measuring it until after its realization or mobilization within a system, through actions surrounding past stress events (Engle 2011).

Attributing adaptations to climate change is not a simple process; it occurs in the context of demographic, cultural, and economic change as well as other societal transformations (Adger *et al.* 2005). Adaptive capacity is context-specific and likely shaped by dynamic variables not easily generalized across contexts (Engle 2011). Engle & Lemos (2010) divides the literature of determinants of adaptive capacity into seven categories: human capital, information and technology, material resources and infrastructure, organization and social capital, political capital, wealth and financial capital, and institutions and entitlements. When the focus is on determinants of community-based adaptation, studies link this capacity to the inherent capacity of communities to self-organize or act collectively (Carpenter *et al.* 2001; Adger 2003; Berkes & Turner 2006). Studies demonstrate the importance of the collective ability, as it is conditioned by social networks, political connections with the government, infrastructure, and technological and information resources of the communities (Pretty & Ward 2001; Ivey *et al.* 2004; Smit & Wandel 2006), to mobilize internal or external financial resources to cover the costs of hard adaptation measures (infrastructure and technology) (Pretty & Ward 2001; Ivey *et al.* 2004).

Given that community-based adaptation is rooted in the ability of human groups to act collectively, there is a clear relationship with the scholarly tradition that analyzes the conditions under which human groups are able to coordinate actions for common-pool resource (CPR) management (Ostrom 1990, 2007; Agrawal 2001). Nevertheless it is important to dispel the belief that all communities have the capacity to govern their local resources. The debate on conditions under which communities could self-organize their resource management is still open; at least 35 factors have been identified as relevant to explain the sustainability of outcomes in these settings (Agrawal 2001).

Taking into account that CPRs are embedded in complex social-ecological systems (SES), Ostrom (2007, 2009) proposed an analytical framework to diagnose the sustainability of such systems. This multi-tier conceptual map is useful in providing a common set of potentially relevant variables that at its broadest level analyzes how (i) the characteristics of the resource system (e.g., watershed and water infrastructure), (ii) the resource units generated by it (e.g., cubic meters of water), (iii) the attributes of users of the system (e.g., social capital, including social norms, rules and internal and external networks facilitating collective action (Woolcock 2001; Adger 2003)) and (iv) its governance structure (e.g., rules devised by CBDWOs) all jointly work together to achieve particular outcomes (e.g., water delivery) in any time and place (Ostrom 2007). These higher order components might affect and be affected by the larger socio-economic, political, and ecological setting in which they are embedded (Ostrom 2007). (Each component of an SES framework includes multiple second-level variables. The analysis of the impact of the variables and their interactions is difficult because the impact of any variable depends on the values of other SES variables. Furthermore, in many complex systems the variables interact in a non-linear way (Ostrom 2009).)

The sustainability of SES systems in the face of external disturbances and the ability of communities coping with such threats to maintain resilient systems has been studied by different scholars (Janssen & Ostrom 2006; Fleischman *et al.* 2010; Coleman 2011). However, the conceptualization and measurement of the type of disturbances affecting SES is quite complex, and differences in severity and length might have profound differences on their impact (Frelich & Reich 1998).

Considering that drinking water provision systems are a particular case of CPRs that include human-made facilities (i.e., piped-water infrastructure) and a natural component, we found that adapting the SES framework to the context of CBDWOs would be useful for guiding our data collection strategy and subsequent analysis. To adapt this framework, we deconstructed the broadest level components (i.e., resource system and units, governance structure, and users) into more detailed variables, whenever necessary. These variables were selected based on a literature review of the key elements that foster collective action in different CPR settings (Agrawal 2001; Ostrom 2007, 2009), and in particular those related to drinking water (Madrigal *et al.* 2011, 2013). We complemented this with emerging theories and empirical findings on adaptive capacity (Polsky *et al.* 2007; Nicholls *et al.* 2007; Engle 2011), with emphasis on social capital (Adger 2003), the role of external actors (Agrawal 2008) and local institutions (Ruijs *et al.* 2011).

There are few studies that analyze the adaptive capacity of CBDWOs. Most notably, Murtinho *et al.* (2013) conducted research in rural Colombia and found that CBDWOs are implementing different adaptation strategies, some relatively expensive and difficult to implement, for coping with water scarcity. The study shows that, despite some communities' capacity to self-organize (creating and modifying their own rules, mobilizing resources, etc.), most of them are not self-sufficient. In fact, 50% of the adaptation strategies implemented were with external financial support. In addition, unsolicited governmental help increases the likelihood of crowding-out communities' efforts to adapt. On the contrary, requested government help for financing adaptation measures tends to reinforce communities' efforts to adapt. The study also shows that self-organized communities are in better positions to bear with relatively high transaction costs associated with requesting external aid from municipal authorities. In fact, one of the most significant barriers to cross-scale interactions for adaptation funding is the relatively high transaction costs (i.e., legal requisites, paperwork, and contracts) (Adger *et al.* 2005).

METHODS AND DATA

Methodological approach and conceptual framework

Our methodological approach relies on the comparison of six similar CBDWOs affected by relatively discrete natural events (e.g., seasonal droughts). Rather than testing hypothesis, this approach requires an in-depth analysis of these cases to study causal pathways (Gerring 2007). This helps explore and generate initial insights into factors and mechanisms affecting the ability of CBDWOs to deal with past droughts.

Our approach, assessing and characterizing adaptive capacity and vulnerability, is closely related to that of Engle (2011). Our basic premise is that adaptive capacity affects vulnerability by modulating sensitivity (how affected a system is after exposure to a disturbance) and exposure (the extent to which the system is physically exposed to external stimuli). Following this logic, Engle (2011) suggests analyzing impacts of recent stress events on similar systems. The lower the negative impacts (lower sensitivity), the more adaptive capacity within the systems. For this study, given that all sampled CBDWOs confront a fairly similar level of climatic exposure, as well as other similarities in infrastructure and contextual factors, we assume that those better performing CBDWOs tend to show a lower sensitivity to droughts, and hence a higher adaptive capacity. The determinants of performance in this context give us an indirect insight into the conditions that affect adaptive capacity and vulnerability of a CBDWO.

Inspired by the analytical framework to study SES developed by Ostrom (2007, 2009) and the literature on adaptation to climate change referred to in the section on theoretical background, we proposed a conceptual framework to analyze the implementation of adaptation measures and the performance of CBDWOs (see Figure 1). This framework also helps us guide the data-gathering strategy. Thus, we collected information from different attributes of the governance structure, users and resource system, mediated by social, economic, and political characteristics. Some of these factors, and their interactions, could affect the ability of communities to coordinate activities affecting performance and the implementation of hard, ecosystem-based, and soft adaptation measures. (This

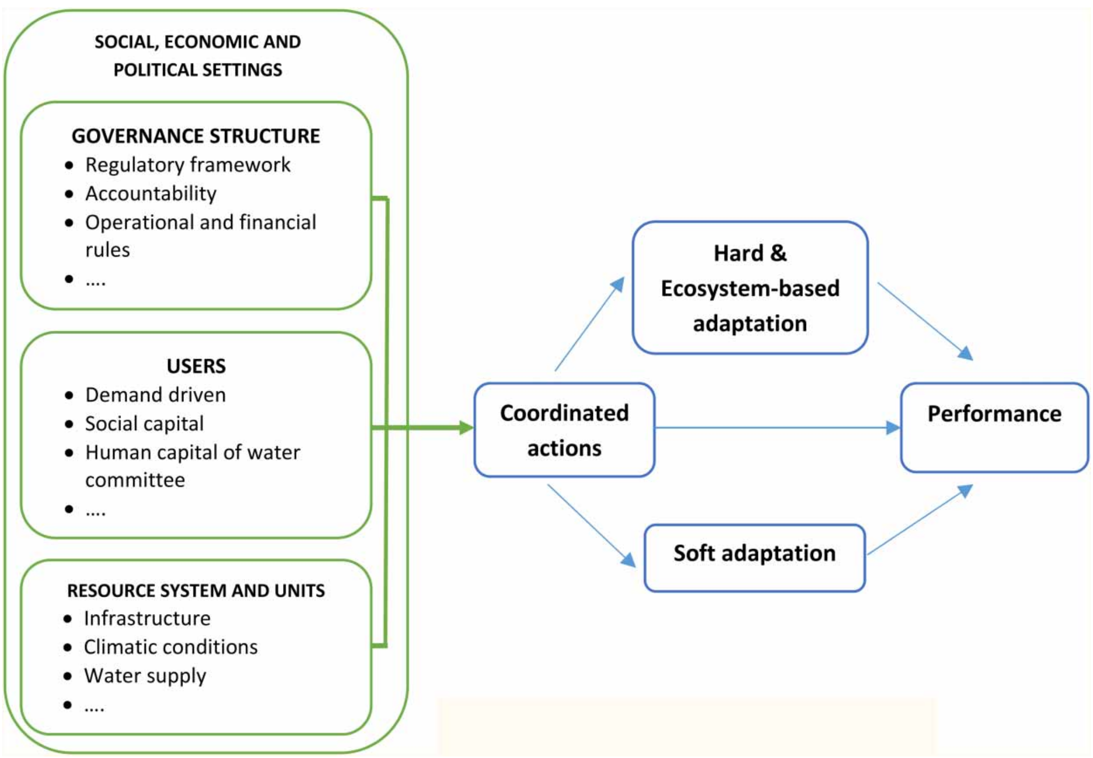

Figure 1 | Conceptual framework.

classification of adaptation measures is arbitrary given the different ways of classifying them. For instance, the division between hard and soft is very common (Margulis & Narain 2010) but others in the water sector tend to classify adaptations within supply and demand options (Kundzewicz *et al.* 2007; Bates *et al.* 2008).) Broadly, hard adaptations include engineering solutions based on infrastructure while soft options depend on policy changes and social capital mobilization (Margulis & Narain 2010). Ecosystem-based adaptations consider that both natural and managed ecosystems can reduce vulnerability to climate-related hazards (Andrade *et al.* 2010).

Another important methodological consideration is our working definition of performance (i.e., the achievement of certain objectives). However, there is no scholarly agreement regarding which objectives must be considered, as well as which methods to use for measuring these outcomes in CBDWOs. On the contrary, there is implicit agreement that performance is a multidimensional concept that includes water quality and availability, and consumer satisfaction, among others (Prokopy & Thorsten 2008; Madrigal *et al.* 2011, 2013). For this study, we are focusing only on water availability at home since this would be much more likely to be affected by seasonal droughts. We characterized this performance dimension using the perception of water consumers regarding piped-water service continuity, as well as the technical evaluation of the water infrastructure (done by a professional in this field).

Case selection and characteristics of sample

The purposive sampling of potential case studies seems a preferred option in comparison to the potential biases and problems associated with pragmatic and completely random selection of case studies (Seawright & Gerring 2008). Given the different techniques for selecting cases depending on research objectives (Gerring 2007; Seawright & Gerring 2008) we chose the most similar case methods, because we were interested in situations where CBDWOs are similar in relation to the exposure to seasonal droughts, and in terms of critical characteristics such as size (number of connections) and socio-economic factors, but differ in terms of some *ex-ante* unobservable variables and the outcomes. (Different studies show the relevance of size regarding CBDWO performance (Kleemeier 2000). Keeping sampled CBDWOs similar in size reduces the number of confounding factors explaining performance.) This strategy would help discern the importance of differences in governance structures and community attributes explaining performance and decisions to adapt.

We selected six out of a total of 23 CBDWOs located in the two driest counties within the Costa Rican dry corridor (ICAA (Costa Rican Institute for Water & Sanitation) 2012). As shown in the next subsection, these CBDWOs share similar socio-economic and climatic indicators. The number of cases does not respond to any statistical criteria to determine sample size; it only provides enough variation in the performance of CBDWOs. We do not aim to extrapolate results for the entire population of CBDWOs. The selection procedure includes two steps. First, in order to select cases similar in size (number of households), we classified 23 CBDWOs according to population size (number of households) and excluded those in the extremes (first and fourth quartile). Second, we randomly selected cases from the remaining population. Table 1 summarizes the main attributes of the CBDWO selected.

Table 1 | Characteristics of organizations sampled

CBDWO[a]	A	B	C	D	E	F
Intra-household connections	108	87	121	220	80	100
Years of operation	18	20	25	30	25	16
Feeder technology	Gravity	Pumping	Gravity	Gravity	Pumping	Pumping
Metering	Yes	Yes	No	Yes	Yes	Yes
# of wells	0	1	0	0	1	1
# of springs	3	0	1	5	0	0
# of storage tanks	2	1	0	2	1	1

[a]The names of the communities have been changed to protect their identities.

All CBDWO administered piped-water systems that deliver water using intra-household connections; no public taps are available. There are no industries, agricultural users or any large consumers of water that use CBDWO delivered water or that share the same water sources. CBDWOs are composed of groups of five to six people appointed by the community, but there are no special quotas based on gender or social status. Eligible voters in all CBDWOs must be the legal house owner (usually adult men).

Study area characteristics

We focused on Costa Rica's dry corridor with the aim of selecting communities affected by similar climatic conditions. These communities are located in the Northern Pacific region, an area characterized by an annual rainfall varying from 1,500 to 2,500 mm and temperatures ranging from an average of 32 °C (day) to 22 °C (night) (IMN (Instituto Meteorológico Nacional) 2009b). However, during extreme dry years, rainfall can be below 1,500 mm/year in the studied sites (Retana *et al.* 2011).

The region of study has a well-defined dry season from December to March (IMN (Instituto Meteorológico Nacional) 2009b). During this period only 4% of total annual precipitation occurs and the highest annual temperatures are recorded (IMN (Instituto Meteorológico Nacional) 2009a). Based on 30 years of data, the highest average monthly precipitation during the dry season could reach 50 mm, while in the rainy season it would not reach more than 300 mm (IMN (Instituto Meteorológico Nacional) 2009a). In addition, the seasonal variations in precipitation and temperature are dependent on the El Niño Southern Oscillation (ENSO). In Costa Rica, 79% of extreme drought (i.e., severe decreases in precipitation) are associated with ENSO's warm phase, known as El Niño (IMN (Instituto Meteorológico Nacional) 2009c). There have been 14 events of ENSO between 1991 and 2010 (National Water Service 2014). During these dry extreme events, the annual precipitation is reduced by 417 mm on average, representing a shortfall of 26%. However, this reduction could be up to 764 mm (43%) in some areas (IMN (Instituto Meteorológico Nacional) 2008). The CBDWOs in this region, including those in our analysis, are exposed to these annual disturbances. The implementation of adaptation measures and the performance during these events are the central focus of this paper.

As a complement to the climatic data, all members of CBDWOs under study clearly perceived that during the dry season the volume of water sources and precipitation both decrease significantly (discrete periodical disturbance). Even though they cannot confirm that water precipitation has decreased on average during the previous years, they do recognize that demographic growth is the most important driver that puts additional pressure on the system during dry periods (slowly built disturbance). Nevertheless, based on information provided by community leaders and official information at the county level (INEC (Instituto Nacional de Estadística y Censos) 2011), all analyzed CBDWOs faced similar demographic growth rates, ranging from 10 to 30% over the last decade.

Coastal areas of the Costa Rican dry corridor have been characterized by a rapid economic and demographic growth catalyzed by the tourism industry. Nevertheless, the CBDWOs under study are located in different areas within the corridor, those with much less direct effect from the tourism industry, a fact that minimizes the likely impact of this economic sector on water demand. In addition, the CBDWOs under study are located in areas sharing similar socio-economic indicators. The communities under study are located in districts ranked as experiencing medium development according to the social development index (IDS) (MIDEPLAN (Ministerio de Planificación Nacional Política y Económica) 2013). The IDS is built on official indicators on education, income, and health. In these areas approximately 50% of the population is occupied in agricultural activities (INEC (Instituto Nacional de Estadística y Censos) 2011). In the 1960s and 1970s, agricultural activities (mostly cattle ranching) led to a rapid advance of the agricultural frontier at the expense of the region's forests, causing changes likely in water cycles (Harvey *et al.* 2005). Nevertheless, this tendency has reduced significantly and the small- and medium-scale agricultural activities that characterize the surrounding areas of the communities under study mostly depend on rain for production.

At the broadest level of governance, the ICAA (the Spanish acronym for the Costa Rican Institute of Water and Sewerage) is responsible for overseeing and supporting CBDWOs. This governmental entity was created in 1961 with the dual purpose of oversight on the one hand, and on the other hand of designing, constructing, and managing drinking water infrastructure in urban and rural communities. From the 1960s to 1990s much rural infrastructure for providing water was constructed by the ICAA and, in some cases, the administration was delegated to local communities.

ICAA provides all CBDWOs with a uniform framework for upward accountability and with regulations that should be followed. However, this governmental entity is enmeshed in a complex institutional hierarchy of overlapping institutions, making it hard to define which one is ultimately responsible for oversight. Moreover, the small size and remoteness of many of these communities create incentives to dedicate limited governmental resources to monitor the biggest organizations near urban areas.

Data

We used three different protocols to collect the data for the analysis.

(i) In-depth interviews with water committee members. We designed an extensive interview with open and closed questions based on the conceptual framework described in the previous section. (This field manual is similar to that of the International Forestry and Resources Institutions (http://www.sitemaker.umich.edu/ifri/home) that studies the relationship between people, institutions and forests. We also relied on similar interviewing protocols designed by Madrigal *et al.* (2011) and Murtinho (2010).) It includes queries on organizational structure, rules, accountability mechanisms, financial aspects, and the adoption of adaptation measures over the last 10 years. In all cases, the president and at least another committee member were present at the time of the interview. We required a total of 6–8 hours, divided into two to three sessions, to complete the interview.

(ii) Household surveys. We surveyed a representative sample of households (30 surveys on average) per village using the systematic sampling method to guarantee geographical representativeness within each community (Scheaffer *et al.* 1987). One of the main components of this survey was the evaluation of performance using different indicators based on perception. Questions on socio-economic characteristics were also included. The survey lasted 15–20 minutes on average and all questions were closed-ended. Three trained enumerators applied the survey.

(iii) Technical evaluation of infrastructure. A hydraulic engineer evaluated the different components of the infrastructure to determine actual and future capacity of the system and to suggest different improvements that should be made in the water systems. This evaluation also contributes to an assessment of the system's performance.

RESULTS AND DISCUSSION

Evaluation of performance of CBDWOs

We used the frequency of water shortages reported by households in the dry season as a proxy of CBDWO performance when coping with water scarcity. This information suggests differences in the sensibility and adaptive capacity to drought in the analyzed communities. As noted in Figure 2, communities A and B have a fairly continuous water service at home (91% and 79% reported no water breakdowns, respectively), while communities E and F are at the other extreme, have frequent water shortages (a severe case is community F where 60% of surveyed people reported daily water shortages). The mixture of results observed in communities C and D might reflect differences in water pressure within the system, causing the water to only reach with difficulty the houses on relatively high land. This latter observation was confirmed by the technical evaluation of the system.

Broadly speaking, analysis of performance based on consumers' perceptions is common for some areas of water research, particularly on water quality (Doria 2010), but the principal concern with these subjective measures is that they may be unrelated to the technical evaluation of the system. However, we found that the perception of water users in relation to performance (frequency of water shortages) strongly matches the technical evaluation conducted in each system (see details in Appendix 1, available in the online

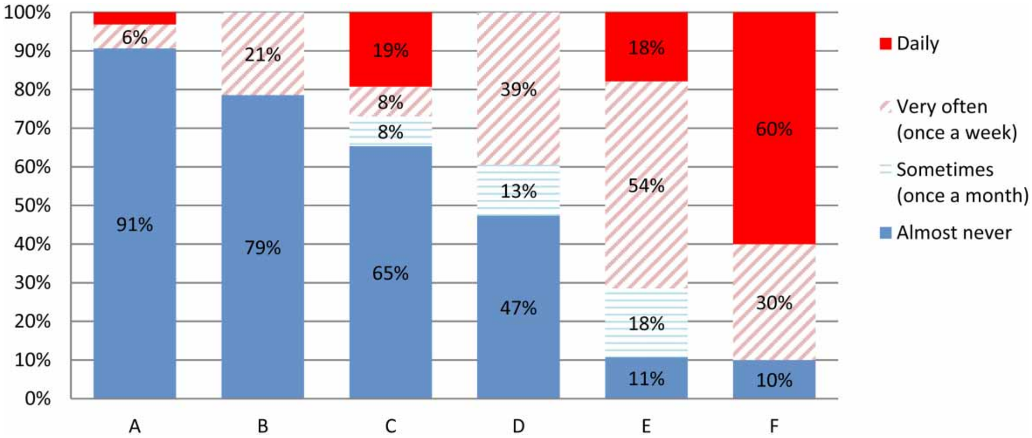

Figure 2 | Frequency of water shortages reported by households in the dry season.

version of this paper). Those low-performing CBDWOs, according to the criteria of consumers, also tend to show technical deficiencies that influence a poor water service, such as low capacity storage tanks, inadequate pressure and conduction indicators, low maintenance of infrastructure and water sources insufficient to meet demand.

We also asked questions regarding the perception of household heads on: (i) equality in water distribution among all households; and (ii) sufficiency of water for daily necessities. Despite the different responses, the ordinal classification of communities tends to be consistent. That is, community A tends to perform better than community B, and so on.

Factors explaining differences in performance

In accordance with our analytical framework, some salient attributes of the resource system and units, users and governance structure, and their interactions, determine the stark differences in performance. The most relevant factors include characteristics of the infrastructure to deliver water, a demand-driven approach and social capital, the human capital of the water committee, financial and operational rules in use by the local organization and accountability mechanisms. We explain these findings below.

Attributes of the resource system and units

Our case selection strategy controlled for some attributes of the infrastructure, as well as spatial and temporal distribution of precipitation (level of exposure). However, there are some other salient attributes of the resource system that affect the performance of CBDWOs. Attributes of the infrastructure, such as feeding technology, storage capacity and water pressure, affect performance. We found that gravity fed systems tend to perform better than pumping systems (except in community B's case). This result can be explained by differences in technical complexity and costs (electricity, fuel) generally associated with pumping systems. It is intrinsically correlated to some attributes of the governance structure, particularly the ability to raise funds and have the technical capacity to run the systems. In short, fuel and electricity costs use up funds in pumping systems, limiting the capacity to buy spare parts in order to respond quickly to system breakdowns and to invest in maintenance measures. Interestingly, despite similar socio-economic conditions, communities E and F raise 25% less money through water fees than higher-performing community B. In addition, the reliability of well operation requires technical abilities that match the hydraulic sophistication of such systems. The lack of technical capacity of all the CBDWOs studied is more notable when there is a need to manage a relatively complex technology such as pumping systems. Finally, the capacity of storage tanks to manage demand peaks, as well as the ability of water pipes and valves to deal with water pressure within the system, were all adequate in higher-performing CBDWOs (A and B), while the rest, especially communities E and F, have serious technical deficiencies in this regard (see Appendix 1).

Attributes of users

Demand-driven approach and social capital. A demand-driven approach is associated with high performance of CBDWOs in different studies around the world (Prokopy 2005; Prokopy *et al.* 2008), particularly in Costa Rica (Madrigal *et al.* 2011). This approach requires a proactive role of communities to solve water provision problems, willingness to pay for investments, and participation in the design of infrastructure and institutions. It implicitly assumes the existence of substantial levels of social capital to promote collective action towards fund raising and self-organization. We found that a demand-driven approach, coupled with the ability of CBDWOs to engage vertically with external entities to draw down on resources and technical and legal assistance (referred to as linking social capital by Woolcock (2001)), tends to be associated with high-performing communities.

We found that all communities have had a central role in the construction and administration of the water systems in their communities. Most of them have committed financial resources and all the necessary labor to build the initial infrastructure years ago (15–20 years ago on average) and subsequent infrastructure improvements during the lifespan of the water systems. However, there is a tendency by high-performing CBDWOs (A and B) to rely on internal funds while low-performing communities (E and F, and to a lesser degree C and D) tend to depend more on clientelist political processes to receive governmental subsidies to build the initial infrastructure. The downside of this latter strategy in the long run is that the allocation of governmental funds for capital replacement and expansion of infrastructure is dependent on volatile political events and scarce governmental budgets. Further, as we discuss below, the absence today of external connectedness to access aid and technical support from the government or other external actors, in addition to a lack of capacity to raise local funds, have limited the chances of low-performing CBDWOs (E and F) to implement costly, but urgently needed, adaptation measures.

In regard to financing development projects with external aid, different authors argue that it might generate dependency and reduce the sense of ownership for recipient communities (Ostrom *et al.* 1993; Gibson *et al.* 2005). The absence of a sense of ownership has been identified as one of the main reasons for the failure of donor-funded infrastructure projects (Gibson *et al.* 2005). It is possible that incentives generated by external aid might diminish the motivations to properly maintain the infrastructure and to enforce cost recovery practices in low-performing communities. Similarly, in the global context of climate change, Raschky & Schwindt (2011) argue that past aid, by reducing *ex-ante* disaster preparedness, might increase the predictability of *ex-post* relief and induce aid recipients to avoid responsibilities.

However, negative stigmatization of external support should be avoided. First, additional empirical work is needed to evaluate the impact of different types of external support (e.g., subsidies and technical assistance at different stages of the life cycle) on the performance of CBDWOs. To determine to what extent aid crowds in or crowds out local efforts is crucial in this regard. Second, as we discuss later, some CBDWOs have had the chance to successfully implement some adaptation measures, thanks to their ability to mobilize external funds to leverage internal resources. Further, it seems that the lack of external help limits the actual capacity of low-performing CBDWOs to adapt. We further discuss these issues in the following sections.

Human capital of water committees. Previous studies (Madrigal *et al.* 2011) have highlighted the relevance of different attributes of the human capital of water boards (e.g., expertise, education, leadership, the participation of women) as important determinants of performance. These elected members of the community play a crucial role in the performance of the water systems because they have direct responsibility for enforcing rules that manage water systems and for solving the different eventualities that arise on a daily basis. In this study, we found that empirical expertise (rather than formal education or training) and credibility of CBDWO members seems to be positively associated with the performance of the water system.

Thanks to a relatively high stability in their positions (5–6 years' tenure, on average), the elected members of communities A and B might have acquired the knowledge and experience (e.g., the basics on hydraulics, water treatment, accounting) to properly manage their local systems, despite the lack of formal training in water management and administration. In stark contrast, community F is characterized by having a de facto non-working committee (absenteeism at regular meetings of most members is notable), with very little experience in their positions (due to high rotation). In addition, different community members have expressed their doubts about the reputation of water board members and their financial management procedures.

Further thoughts on the human capital of water boards are pertinent. First, high-performing communities (most notably A and B) include very competent plumbers with enough expertise to manage the infrastructure correctly. In addition (and as opposed to the other CBDWOs), this position is a full-time job, paid and accountable to the water committee. Second, the stability in positions of water board members is not a sufficient condition for high performance CBDWOs. We found that community D's president has 30 years' experience in different positions, while members of community E have 6 years' average experience in different positions. This contradicts the results of Prokopy *et al.* (2008), which found that the length of time committee members and maintenance operators served in their respective roles positively affects the physical performance of these systems. This intriguing result might indicate that other contextual variables are more important to explain performance; it also suggests that some incentives crowd out the participation of other qualified members of the community in the administration of their water systems. Third, in other contexts, gender-balanced water boards and, more importantly, situations in which women have real potential to affect decision-making processes tend to be associated with higher performance (van Wijk-Sijbesma 1998; Madrigal *et al.* 2011) although less definitive findings are also found (Prokopy 2004). In all the analyzed CBDWOs, women represent around 40% of water boards on average, which is suggestive regarding their skills and self-confidence. However, given the lack of variation of this indicator across organizations and the absence of additional information on the active role of women in decision-making processes, we cannot suggest any substantive relationship between women's participation on water committees and performance.

Governance structure. Governance structure is a broad concept that includes the different types of rules devised and enforced by CBDWOs (e.g., operational and financial rules) and the national legal framework in which they are embedded (e.g., national regulatory framework). The relevance of these attributes to explaining collective action is generally well-documented in the literature of CPRs (Ostrom 1990, 2009; Agrawal 2001) and in the context of drinking water provision (Saleth & Dinar 2004; Madrigal *et al.* 2011). We present the most distinctive features of the governance structure that seem to affect performance in the analyzed CBDWOs.

In fact, we found little evidence that ICAA exerts any direct influence on the decisions taken by CBDWOs under analysis. For instance, only a few CBDWOs submitted annual reports to ICAA on an irregular basis; no feedback exists based on this delivery. Also, visits from ICAA staff are scarce and irregular and have no specific purpose, according to water board members. In these contexts, it is very likely that mechanisms for downward accountability (i.e., accountability from water board members to the community) play a key role in the governance structure, and facilitate consumer desires being taken into account in decision-making processes.

According to Ribot *et al.* (2006), elections are seen as the mechanism that ensures downward accountability; however, this concept is much broader and includes other means, such as public audited reports, general assemblies, and other informal mechanisms. We found that most CBDWOs have different mechanisms (such as annual assemblies in which written reports are presented and discussed among community members) that guaranteed those responsible for local administration of water systems are held accountable to local populations. Interestingly, according to our interviews, we noticed that the lowest performing communities (E and F) lack some indicators of downward accountability, such as audited financial reports and minimal procedures to guarantee fund management transparency, written working plans, and well-defined periodical elections, among others. In addition, these communities lack procedures and rules to coordinate administrative duties, systematic channels to respond to water breakdowns, and comprehensible and enforceable rules for sanctioning water fee debtors.

On the other hand, differences in the type of rules for cost recovery and its enforcement, instead of the socio-economic status of communities, seem to explain variations in the financial capabilities of CBDWOs. These capabilities tend to be associated with performance as well, and even though some organizations show better cost recovery practices than others, none of the CBDWOs under analysis have the capacity to fully recover capital costs. One possible explanation for this is that despite the fact that all CBDWOs must charge water fees defined by the national authority regulating public services, the CBDWOs under study charge a lower fee than that defined by this entity.

In addition, all CBDWOs show poor enforcement of sanctions for water debtors, particularly communities E and F. In fact, the low-performing community F has incomes 20–25% lower than that of high-performing community B, despite reporting similar expenses for their pumping fed systems (which require substantial amounts of cash to pay for electricity costs). Savings are absent in community F, while community B has at least enough cash and spare parts to deal with day-to-day operational challenges. Alternatively, all organizations with gravity fed systems generate savings (cash and spare parts). In particular, high-performing community A has savings four times higher than that of the other two communities (C and D). Nevertheless, even in this case, these savings are not enough to cover relatively large investments, such as a new storage tank.

Adaptation measures implemented to deal with seasonal droughts

We identified different adaptation measures consciously taken by CBDWOs to deal with water scarcity, especially during seasonal droughts over the last 10 years. These measures had been implemented after initial construction of the system and are still functional. We assessed this using a predefined list of potential adaptation measures, asking CBDWO leaders if they have implemented each option and the reasons for doing so. Table 2 summarizes this information.

As indicated in Table 2, the existent measures are grouped into hard, soft, and ecosystem-based adaptation practices. Interviews with local leaders revealed that necessity triggers reactive, rather than preventive, implementation of adaptation measures. The preferred reactive measures are soft and hard options, while there is a tendency to perceive ecosystem-based options as preventive measures. This accords with other reports in the literature stating that the adaptation already occurring in different systems is reactive, in that it is triggered by the innate ability to adapt to one's environment, and by past or current events (Adger *et al.* 2005; Engle 2011). Once a capacity or productivity threshold is reached (demand equals supply capacity), CBDWOs initiate actions on behalf of community members so they may adapt. In other words, local villagers need to observe some water scarcity before they invest in defensive measures. (Similarly, Ostrom (2009) and Wade (1994) argue the incentive to self-organize depends positively on the scarcity of the resource. However, Ostrom (2009) suggests that this could be a curvilinear relationship. If a resource is already depleted or apparently very abundant, users would not see a need to manage for the future.)

We also found that the implementation of adaptation measures tends to follow a sequential order. CBDWOs start with soft adaptation measures such as rationing and bans on certain activities. After more severe water scarcity and/or limited realization of expected benefits, CBDWOs start to implement hard options, which tend to be more effective. In this regard, metering is the preferred option, then building additional tanks and wells. Ecosystem-based options are located at the far end of this implementation spectrum. These findings take into account the fact that in

Table 2 | Adaptation measures implemented by CBDWOs

	CBDWO					
Adaptation measures	**A**	**B**	**C**	**D**	**E**	**F**
Hard						
Metering devices at home	1	1	1	1	1	0
Additional storage tanks	1	1	0	1	0	0
Additional wells	0	0	0	1	0	0
Soft						
Rationing water during certain hours	0	0	1	0	1	1
Ban for certain water uses (animals and gardening)	0	0	0	1	1	0
Water saving campaigns	0	0	0	0	1	1
Ecosystem based						
Purchase of land to protect water sources	1	0	0	1	0	0

1 = existing/in use; 0 = non-existing.

cases of extreme need, more than one adaptation measure is implemented and maintained over time.

The relationship between actual performance (i.e., low sensitivity to seasonal droughts) and the number and type of adaptation measures merits attention. Even though the adaptations listed in Table 2 most likely have a positive impact on performance, it is difficult to find a clear relationship between the number of adaptation measures and actual performance. Rather, the type of adaptation measure seems to be relevant. It seems that low-performing CBDWOs (E and F) tend to use soft adaptation measures, which might be less effective (and cheaper) to deal with scarcity problems. Even high-performing CBDWOs (A and B) initially implemented soft measures; they later made an additional effort to invest in measures that were perceived as more effective (mostly hard) in overcoming the problems from having exceeded the threshold capacity of the water system. Interestingly, community D has invested in additional wells and tanks. Unfortunately for them, these defensive measures were not technically designed to match the demand of the system, and hence are insufficient to cope with users' consumption.

Factors facilitating (or preventing) the implementation of adaptation measures at the community level

The results indicate that the determinants of the implementation of adaptation measures are closely related to most of the enabling conditions that facilitate the high performance of CBDWOs. Thus, adaptation depends on different attributes of the resource system, the governance structure and the community of users, as well as their interactions.

Some attributes of the resource system conditioned the implementation of adaptation measures. In particular, location of communities limits adaptation options. For instance, an additional spring to augment water supply is an available option for some CBDWOs while for others it is unfeasible (at a reasonable cost) to implement, given the lack of additional springs in nearby locations. Nevertheless, we found that other aspects related to the governance structure and attributes of the local villagers seem to be more relevant as factors enabling adaptation.

The implementation of adaptation measures, especially those that are capital-intensive, is mostly facilitated by the capacity of communities to act collectively to mobilize internal and external funds. Table 3 summarizes information regarding this.

Despite the elevated costs of metering systems, tanks and land purchasing for the protection of springs, some communities (most notably community A) have had the capacity to finance all these investments with their own resources (savings or additional contributions). Nevertheless, the high-performing community B has solicited external help from the central government and other donors to co-finance their capital investments in adaptation. The capacity of water board members to nurture relationships of connectedness with external donors, and their willingness and capacity to deal with complicated bureaucratic processes, has facilitated adaptation. Thus, the solicited external aid crowded in the local efforts to adapt, as it sped up a process that had already started.

In other cases, such as community D, our interviews helped to highlight the fact that without external aid, most likely investments in an additional storage tank and well would have not been made. Further, communities E and F have not implemented hard adaptation measures despite recognizing the urgent need to do so (with the exception of E vis-à-vis metering). According to water board members,

Table 3 | Sources of funding for existing hard and ecosystem-based adaptation

	CBDWO					
	A	**B**	**C**	**D**	**E**	**F**
Metering systems	Community	Community + external	External	Community	Community	N/A
Additional wells	N/A	N/A	N/A	Community + external	N/A	N/A
Construction of storage tanks	Community	N/A	N/A	External	N/A	N/A
Purchase of land for protection of springs	Community	N/A	N/A	Community	N/A	N/A

N/A: non-existing adaptation measure.

the elevated costs of these investments are the most significant barriers for their implementation. In fact, estimated costs of prioritized adaptation measures, supported by technical criteria and including installation of pressure valves, prospecting of a new source, and construction of a well, ranged from US$30,000 to US$40,000.

Water board members in these communities also recognized that despite the difficulties in collecting funds locally, they lack the political connectedness to solicit external funds and technical guidance. Nevertheless, we do believe that more research is needed to further evaluate whether the absence of such investments is attributable to other reasons, such as dependency on unsolicited help, unwillingness of local households to cover the investment costs due to other community development priorities, capacity to use additional water sources or lack of trust in CBDWO operation. The degree to which external aid crowds in or crowds out local willingness to finance adaptation is another issue of central relevance for further research.

It is important to highlight the notion that technical knowledge critically conditions the success of most adaptation investments. That means that the costs of planning adaptations need to include technical studies that support at least the minimal aspects of design (e.g., location and depth of a well). We found cases in which the absence of such knowledge led CBDWOs to invest significant amounts of money in adaptations that did not deliver the expected benefits, which in turn caused financial losses, communal uneasiness, and an inability to cope with drought. Unfortunately, community F is notorious for this, with a failed costly well; a few other communities also have some failures (e.g., community D's additional storage tanks of inadequate dimensions).

Another important consideration is the perception of CBDWOs regarding future scarcity problems in their communities and their plans to overcome such problems. Five out of the six communities (community A was the exception) perceive serious scarcity problems within a 10-year time frame if no adaptation measure is taken. Demographic growth, more elevated temperatures, and a decrease in water supply at the source were the main factors indicated as causes of scarcity. Further, communities E and F anticipate a catastrophic situation if the next dry season extends by 1 or 2 months. However, while most water board members identified solutions from the supply side as problem solvers, there are no clear plans, supported by technical criteria, on when and where to start or how to finance the investments. In addition, communities E and F claimed that without technical and financial external support, they are condemned to suffer the consequences of water scarcity. A study on CBDWOs in Colombia (Murtinho *et al.* 2013) reported that despite the effort of communities to finance their adaptation investments, external aid is needed in the long run. However, unsolicited help most likely crowds out local efforts to adapt, while requested aid tends to crowd in local efforts.

CONCLUSIONS

Our findings contribute to the ongoing debate on devising adaptation strategies for climate change in communities of the developing world, while they avoid the tendency to suggest policy prescriptions that fail to capture the particular socio-ecological interactions at each site. We show that community-based adaptation for drinking water systems is context dependent and results from a complex interaction of attributes of the natural base and the infrastructure in which they reside, and the attributes of local users and the governance structure in which they interact.

Thus, it is very likely that single uniform solutions prescribed to strengthen the adaptive capacity of CBDWOs would not work in all contexts. An integral diagnosis of the underlying causes of vulnerability is necessary to guide policy interventions, including targeted subsidies for financing adaptation. In addition, this diagnosis should consider the capacities and resources for dealing with the technical complexity of the water systems, the ability to collect local resources and have outside connections to access additional funds and specialized advice. The existence of clearly defined and efficient procedures of accountability and administrative managing are also important in this regard.

We identified adaptation measures against droughts and the principal constraints for implementation. We found that CBDWOs implement hard, soft, and ecosystem-based adaptation measures. The decisions in this regard are reactive, tend to follow a sequential order and are context dependent.

One of the main factors that facilitate capital-intensive adaptation measures is the ability of CBDWOs to mobilize internal or external financial resources, which further depend on social capital (internal and external networks) and the governance structure.

Our approach, learning from the past in order to predict future adaptive capacity to climate change, could provide initial insights into the ability to adapt before expected disturbances are realized. However, we acknowledge that future events can be more intense and unpredictable and CBDWOs that have been successful in adapting to past droughts might not have the capacity to deal with this new scenario. To better assess the latent capacity of CBDWOs we need to have downscaled models that identify characteristics and potential impacts of future climatic events on groundwater and surface water availability and quality. The interaction and relative importance of climatic disturbances with other socio-economic stressors is crucial as well. This information would allow the defining of those system thresholds and specific adaptation measures needed to cope with these adverse events. This would help overcome the limits of the static analysis of actual performance as an indicator of the sensitivity of the water systems to future exposure to drought events.

We also acknowledge that more research is needed to support policy interventions. First, it is important to analyze how policies and governance structures at multiple levels need to be linked as essential components of a strategy for the long-term provision of drinking water in rural landscapes. This is particularly relevant given that most CBDWOs lack the legal and financial capacity to alter human decisions on land use in these zones, thereby limiting their ability to influence system productivity and hence the amount of water that feeds their systems. Further, CBDWOs have limited, if any, capacity to alter the drivers of water scarcity in their systems due to an increased demand for water for irrigation, industries, and growing populations, among others. Public policies need to explicitly account for such interdependencies to minimize the external stressors that affect the ability of CBDWOs to provide a reliable water service in their communities.

Last but not least, the external validity of the initial insights presented in this paper need to be validated using larger samples. This additional research might emphasize the effect of external aid and technical support on the performance of CBDWOs and their ability to implement adaptation measures. The potential complementarities or tradeoffs between community-based level and household level adaptation should be further explored. The potential role for development assistance in supporting adaptive capacity might be considered, largely because of the extensive overlap between these two fields (Ayers & Hug 2008; van Drunen *et al.* 2008). Besides the central issue of how to finance climate change adaptation, the potential perverse incentives generated by external support on adaptation must be carefully considered, in order to avoid dependency and underinvestment in climate change preparedness.

ACKNOWLEDGEMENTS

Economic support from the International Development Research Center (IDRC), through the project 'Strengthening research capacity in environmental economics for adaptation to climate change', is gratefully acknowledged. We thank Walter Ubal for his support in developing this research. We are grateful to Instituto Costarricense de Acueductos y Alcantarillados (ICAA) for facilitating data sets; community members for providing information and two anonymous reviewers for helpful comments and suggestions. All errors and omissions remain the full responsibility of the authors.

REFERENCES

Adger, W. N. 2003 Social capital, collective action, and adaptation to climate change. *Economic Geography* **79** (4), 387–404.

Adger, W. N. 2006 Vulnerability. *Global Environmental Change* **16** (3), 268–281.

Adger, W. N., Arnell, N. W. & Tompkins, E. L. 2005 Successful adaptation to climate change across scales. *Global Environmental Change* **15** (2), 77–86.

Adger, W. N., Agrawala, S., Mirza, M. M. Q., Conde, C., O'Brien, K., Pulhin, J., Pulwarty, R., Smit, B. & Takahashi, K. 2007 Assessment of adaptation practices, options, constraints and capacity. In: *Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change* (M. L. Parry, O. F. Canziani, J. P. Palutikof,

P. J. van der Linden & C. E. Hanson, eds). Cambridge University Press, Cambridge, UK, pp. 717–743.

Agrawal, A. 2001 Common property institutions and sustainable governance of resources. *World Development* **29** (10), 1649–1672.

Agrawal, A. 2008 *The Role of Local Institutions in Adaptation to Climate Change*. Social Dimensions of Climate Change, Social Development Department, The World Bank, Washington, DC.

Andrade, A., Herrera, B. & Cazzolla, R. (eds) 2010 *Building Resilience to Climate Change: Ecosystem-based adaptation and lessons from the field*. IUCN, Gland, Switzerland.

AVINA 2011 *Democratic Governance Models for Access to Water in Latin America* [*Modelos de Gobernabilidad Democrática para el Acceso al Agua en América Latina*]. AVINA Foundation. www.avina.net.

Ayers, J. M. & Hug, S. 2008 Supporting adaptation to climate change: what role for official development assistance? In: *Annual Conference on Development's Invisible Hands: Development Futures in a Changing Climate*. Church House, Westminster, London.

Bates, B. C., Kundzewicz, Z. W., Wu, S. & Palutikof, J. P. 2008 *Climate Change and Water. Technical Paper of the Intergovermental Panel on Climate Change*. IPCC Secretariat, Geneva, p. 210.

Berkes, F. & Turner, N. J. 2006 Knowledge, learning and the evolution of conservation practice for social-ecological system resilience. *Human Ecology* **34** (4), 479–494.

Carpenter, S., Walker, B., Anderies, J. M. & Abel, N. 2001 From metaphor to measurement: resilience of what to what? *Ecosystems* **4** (8), 765–781.

Coleman, E. A. 2011 Common property rights, adaptive capacity, and response to forest disturbance. *Global Environmental Change* **21** (3), 855–865.

Doria, M. F. 2010 Factors influencing public perception of drinking water quality. *Water Policy* **12** (1), 1–19.

Engle, N. L. 2011 Adaptive capacity and its assessment. *Global Environmental Change* **21** (2), 647–656.

Engle, N. L. & Lemos, M. C. 2010 Unpacking governance: building adaptive capacity to climate change of river basins in Brazil. *Global Environmental Change* **20** (1), 4–13.

Fleischman, F. D., Boenning, K., Garcia-Lopez, G. A., Mincey, S., Schmitt-Harsh, M., Daedlow, K., Lopez, M. C., Basurto, X., Fischer, B. & Ostrom, E. 2010 Disturbance, response, and persistence in self-organized forested communities: analysis of robustness and resilience in five communities in Southern Indiana. *Ecology and Society* **15** (4), 9.

Frelich, L. E. & Reich, P. B. 1998 Disturbance severity and threshold responses in the boreal forest. *Conservation Ecology* **2** (2), 7.

Gerring, J. 2007 *Case Study Research: Principles and Practices*. Cambridge University Press, New York.

Gibson, C., Andersson, K., Ostrom, E. & Shivakumar, S. 2005 *The Samaritan's Dilemma: The Political Economy of Development Aid*. Oxford University Press, Oxford, UK.

Harvey, C., Alpizar, F., Chacón, M. & Madrigal, R. 2005 Assessing Linkages between Agriculture and Biodiversity in Central America: Historical Overview and Future Perspectives. Mesoamerican & Caribbean Region, Conservation Science Program. The Nature Conservancy (TNC), San José, Costa Rica. http://eprints.eriub.org/1058/1/Harvey_et_al._2005_AG_ and_BD_in_C.Am.pdf.

ICAA (Costa Rican Institute for Water, Sanitation) 2012 *CBDWO Database – Chorotega Region*. Departamento de Acueductos Rurales, San José, Costa Rica.

ICAA (Costa Rican Institute for Water, Sanitation), OPS (Pan-American Health Organization), OMS (World Health Organization) 2002 *Sectoral Analysis of Water and Sanitation in Costa Rica*. ICAA, San José, Costa Rica.

IMN (Instituto Meteorológico Nacional) 2008 Climate Variability and Climate Change in Costa Rica. In *Second National Communication on Climate Change* [*Clima, Variabilidad y Cambio Climático en Costa Rica. Segunda Comunicación Nacional Sobre Cambio Climático*]. IMN, San José, Costa Rica. http://cglobal.imn.ac.cr/sites/default/files/documentos/el_clima_variabilidad_y_cambio_climatico_en_cr_version_final.pdf (accessed 7 March 2012).

IMN (Instituto Meteorológico Nacional) 2009a *Climate Atlas of Costa Rica* [*Atlas Climático de Costa Rica*]. http://www.imn.ac.cr/mapa_clima/interactivo/index.html (accessed 7 March 2012).

IMN (Instituto Meteorológico Nacional) 2009b *Weather in Costa Rica: North Pacific. Costa Rica* [*Clima en Costa Rica: Pacífico Norte. Costa Rica*]. http://www.imn.ac.cr/educacion/climacr/pacifico_norte.html (accessed 30 October 2014).

IMN (Instituto Meteorológico Nacional) 2009c *The ENSO phenomenon* [*El Fenómeno del ENOS* (Niño Oscilación del Sur)]. http://www.imn.ac.cr/educacion/enos.html (accessed 31 October 2014).

INEC (Instituto Nacional de Estadística y Censos) 2011 X National Census of Population and VI Household Survey: General Results [X Censo Nacional de Población y VI de Vivienda: Resultados Generales], 1st edn. San José, Costa Rica. http://www.inec.go.cr/A/MS/Censos/Censo%202011/Cifras%20preliminares/15.%20Resultados%20Generales%20Censo%202011.pdf (accessed 31 October 2014)

Ivey, J. L., Smithers, J., de Loë, R. C. & Kreutzwiser, R. D. 2004 Community capacity for adaptation to climate-induced water shortages: linking institutional complexity and local actors. *Environmental Management* **33** (1), 36–47.

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** (3), 237–239.

Kleemeier, E. 2000 The impact of participation on sustainability: an analysis of the Malawi rural piped scheme program. *World Development* **28** (5), 929–944.

Kundzewicz, Z. W., Mata, L. J., Arnell, N. W., Döll, P., Kabat, P., Jiménez, B., Miller, K. A., Oki, T., Sen, Z. & Shiklomanov,

I. A. 2007 Freshwater resources and their management. In: *Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change* (M. L. Parry, O. F. Canziani, J. P. Palutikof, P. J. van der Linden & C. E. Hanson, eds). Cambridge University Press, Cambridge, UK, pp. 173–210.

Kundzewicz, Z. W., Mata, L. J., Arnell, N. W. & Döll, P. 2008 The implications of projected climate change for freshwater resources and their management. *Hydrological Sciences* **53** (1), 3–10.

Madrigal, R., Alpízar, F. & Schlüter, A. 2011 Determinants of performance of community-based drinking water organizations. *World Development* **39** (9), 1663–1675.

Madrigal, R., Alpízar, F. & Schlüter, A. 2013 Public perceptions of the performance of community-based drinking water organizations in Costa Rica. *Water Resources and Rural Development* **1–2**, 43–66.

Margulis, S. & Narain, U. 2010 The costs to developing countries of adapting to climate change : new methods and estimates - the global report of the economics of adaptation to climate change study. World Bank, Washington, DC. Available at: http://documents.worldbank.org/curated/en/2010/01/12563514/costs-developing-countries-adapting-climate-change-new-methods-estimates-global-report-economics-adaptation-climate-change-study (accessed 10 April 2015).

MIDEPLAN, (Ministerio de Planificación Nacional Política y Económica) 2013 *Social Development Index 2013 [Indice de Desarrollo Social 2013]*. Área de Análisis del Desarrollo, San José, Costa Rica. www.mideplan.go.cr.

Murtinho, F. 2010 Understanding adaptation to climate variability: Challenges and opportunities of community based water management. In: *ICARUS Workshop Climate Vulnerability and Adaptation: Theory and Cases*. 11–13 February 2010, University of Illinois, Urbana-Champaign, IL, pp. 1–23.

Murtinho, F. & Hayes, T. M. 2011 Adaptation in resource-dependent communities: a call for greater methodological clarity in adaptation field research. *Society & Natural Resources* **25** (5), 1–10.

Murtinho, F., Eakin, H., López-Carr, D. & Hayes, T. M. 2013 Does external funding help adaptation? Evidence from community-based water management in the Colombian Andes. *Environmental Management* **52** (5), 1103–1114.

National Water Service 2014 *Changes to the Oceanic Niño Index (ONI)*. http://www.cpc.ncep.noaa.gov/products/analysis_monitoring/ensostuff/ensoyears.shtml (accessed 30 October 2014).

Nicholls, R. J., Wong, P. P., Burkett, V. R., Codignotto, J. O., Hay, J. E., McLean, R. F., Ragoonaden, S. & Woodroffe, C. D. 2007 Coastal systems and low-lying areas. In: *Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change* (M. L. Parry, O. F. Canziani, J. P. Palutikof, P. J. van der Linden & C. E. Hanson, eds). Cambridge University Press, Cambridge, UK, pp. 315–356.

Ostrom, E. 1990 *Governing the Commons: The Evolution of Institutions for Collective Action*. Cambridge University Press, Cambridge, UK.

Ostrom, E. 2007 A diagnostic approach for going beyond panaceas. *Proceedings of the National Academy of Sciences of the United States of America* **104** (39), 15181–15187.

Ostrom, E. 2009 A general framework for analyzing sustainability of social-ecological systems. *Science* **325** (5939), 419–422.

Ostrom, E., Schroeder, L. & Wynne, S. 1993 *Institutional Incentives and Sustainable Development: Infrastructure Policies in Perspective*. Westview Press, Boulder, CO, USA.

Polsky, C., Neff, R. & Yarnal, B. 2007 Building comparable global change vulnerability assessments: the vulnerability scoping diagram. *Global Environmental Change* **17** (3–4), 472–485.

Pretty, J. & Ward, H. 2001 Social capital and the environment. *World Development* **29** (2), 209–227.

Prokopy, L. S. 2004 Women's participation in rural water supply projects in India: is it moving beyond tokenism and does it matter? *Water Policy* **6** (2), 103–116.

Prokopy, L. S. 2005 The relationship between participation and project outcomes: evidence from rural water supply projects in India. *World Development* **33** (11), 1801–1819.

Prokopy, L. S. & Thorsten, R. 2008 The role of wealth, income, and social capital in determining a household's choice to participate in rural water-supply projects in Peru. *Environment and Planning C: Government and Policy* **26** (6), 1162–1176.

Prokopy, L. S., Thorsten, R., Bakalian, A. & Wakeman, W. 2008 Evaluating the role of postconstruction support in sustaining drinking water projects: evidence from Peru. *Journal of Planning Education and Research* **27** (3), 294–305.

Raschky, P. A. & Schwindt, M. 2011 *Aid, Catastrophes and the Samaritan's Dilemma*. *Working Paper*. http://users.monash.edu.au/~praschky/aid_disasters_11052011.pdf (accessed 7 March 2012).

Retana, J., Araya, C., Sanabria, N., Alvarado, L., Solano, J., Barrientos, O., Solera, M., Alfaro, M. & Araya, D. 2011 *Risk Analysis of Current Water Sector in Costa Rica on Climate Change to contribute to Improve Human Development* [*Análisis del Riesgo Actual del Sector Hídrico de Costa Rica ante el Cambio Climático para Contribuir a Mejorar el Desarrollo Humano*]. http://cglobal.imn.ac.cr/sites/default/files/documentos/analisis_del_riesgo_actual_del_sector_hidrico_de_costa_rica_ante_el_cambio_climatico.pdf (accessed 31 October 2014).

Ribot, J. C., Agrawal, A. & Larson, A. M. 2006 Recentralizing while decentralizing: how national governments reappropriate forest resources. *World Development* **34** (11), 1864–1886.

Ruijs, A., de Bel, M., Kononen, M., Linderhof, V. & Polman, N. 2011 Adapting to climate variability: learning from past experience and the role of institutions. *Social Development Papers. Social Dimensions of Climate Change. The World Bank* **64372** (124), 32.

Saleth, R. M. & Dinar, A. 2004 *The Institutional Economics of Water: a Cross-Country Analysis of Institutions and Performance*. Edward Elgar, Cheltenham, UK.

Scheaffer, R. L., Mendenhall, W. & Ott, L. 1987 *Elementary Survey Sampling*. Duxbury Press, Belmont, CA, USA.

Seawright, J. & Gerring, J. 2008 Case selection techniques in case study research: a menu of qualitative and quantitative options. *Political Research Quarterly* **61** (2), 294–308.

Smit, B. & Wandel, J. 2006 Adaptation, adaptive capacity and vulnerability. *Global Environmental Change* **16** (3), 282–292.

UNGA 2010 *The Human Right to Water and Sanitation*, 108th plenary meeting. http://www.un.org/es/comun/docs/?symbol=A/RES/64/292&lang=E (accessed 7 March 2012).

Van Drunen, M., Barz, P., Burger, E., Çelik, K., Dellink, R., Dresner, S., Femia, A., Gil-jum, S., van Herwijnen, M., Hinterberger, F., Kalay-cıoğlu, S., Kemppainen, S., Lutter, S., Lutz, C., Luukkanen, J., Pihlajamäki, M., Stocker, A., Tudini, A., Venn, A., Vehmas, J. & Wiebe, K. 2008 *Indicator-Based Evaluation of Interlinkages Between Different Sustainable Development Objectives. Case Studies Methods, Tools and Models for Assessment of SD Interlinkages*. http://www.indi-link.net/images/stories/Download/indi-link_d2.4_final.pdf (accessed 7 March 2012).

Van Wijk-Sijbesma, C. 1998 *Gender in Water Resources Management, Water Supply and Sanitation: Roles and Realities Revisited*. IRC International Water and Sanitation Centre, Delft, The Netherlands.

Wade, R. 1994 *Village Republics: Economic Conditions for Collective Action in South India*. ICS Press, San Francisco, CA, USA.

Wolf, J., Adger, W. N., Lorenzoni, I., Abrahamson, V. & Raine, R. 2010 Social capital, individual responses to heat waves and climate change adaptation: an empirical study of two UK cities. *Global Environmental Change* **20** (1), 44–52.

Woolcock, M. 2001 The place of social capital in understanding social and economic outcomes. *Canadian Journal of Policy Research* **2** (1), 11–17.

First received 17 December 2013; accepted in revised form 6 March 2015. Available online 9 April 2015