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# Vulnerability and adaptation in a dryland community of the Elqui Valley, Chile

**Gwendolynne Young · Humberto Zavala · Johanna Wandel · Barry Smit · Sonia Salas · Elizabeth Jimenez · Melitta Fiebig · Roxana Espinoza · Harry Diaz · Jorge Cepeda**

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**Abstract** Livelihoods in drylands are already challenged by the demands of climate variability, and climate change is expected to have further implications for water resource availability in these regions. This paper characterizes the vulnerability of an irrigation-dependent agricultural community located in the Elqui River Basin of Northern Chile to water and climate-related conditions in light of climate change. The paper documents the exposures and sensitivities faced by the community in light of current water shortages, and identifies their ability to manage these exposures under a changing climate. The IPCC identifies potentially increased aridity in this region with climate change; furthermore, the Elqui River is fed by snowmelt and glaciers, and its flows will be affected by a warming climate. Community vulnerability occurs within a broader physical, economic, political and social context, and vulnerability in the community varies amongst occupations, resource uses and accessibility

G. Young · J. Wandel · B. Smit (✉)
Department of Geography, University of Guelph, Guelph, ON, N1G 2W1, Canada
e-mail: bsmit@uoguelph.ca

H. Zavala
Department of Civil Engineering, University of La Serena, La Serena, Chile

S. Salas · E. Jimenez · R. Espinoza
Department of Psychology, University of La Serena, La Serena, Chile

M. Fiebig
Department of Mathematics, University of La Serena, La Serena, Chile

H. Diaz
Department of Sociology and Social Studies, University of Regina, Regina, Canada

J. Cepeda
Department of Biology, University of La Serena, La Serena, Chile

to water resources, making some more susceptible to changing conditions in the future. This case study highlights the need for adaptation to current land and water management practices to maintain livelihoods in the face of changes many people are not expecting.

## 1 Introduction

It is widely accepted that climate change, largely attributed to anthropogenic emissions of greenhouse gases, is accelerating and is a cause for international concern. The global average temperature has increased by 0.76°C in the last 150 years, with 11 of the last 12 years (1995–2006) ranking among the 12 warmest years in the instrumental record, since 1850 (IPCC 2007). Temperature increases, changes in precipitation, and interactions with climate variability associated with phenomena such as El Niño Southern Oscillation (ENSO) are projected to alter the frequency, intensity and/or extent of climatic and weather extremes (IPCC 2007). These changing conditions are expected to affect natural resources and human livelihoods in many regions. In particular, water resources are highly sensitive to climate variability and change with implications for water-dependent communities and sectors (Miller et al. 1997; Arnell 2004; Gerten et al. 2007). The vulnerability of communities to climate change is influenced by the ways in which they are affected by climate conditions and by the manner in which they can moderate effects or risks through adaptive strategies (Adger 2006; Füssel and Klein 2006; Smit and Wandel 2006).

For thousands of years societies have adapted their cultures and economies to their geography, including the prevailing climatic and hydrologic environments, with varying degrees of success. Changes in climate and water could have severe implications for ecosystems, economic development and social well-being (Beniston 2003; IPCC 2007). In particular, arid and semi-arid areas are often challenged by the demands of existing climate variability, and it is expected that climate change will have significant implications for water resources in these areas (Miller et al. 1997; Sivakumar et al. 2005). As changes in precipitation, evaporation, infiltration and runoff affect hydrologic processes, these drylands are expected to experience further decreases in moisture availability (Arnell and Liu 2001; Mata and Campos 2001). This could have serious implications for water use, water management and livelihoods for the nearly 40% of the world's people who inhabit dryland areas (IISD 2003). The Intergovernmental Panel on Climate Change (IPCC) estimates that by 2080 nearly three billion additional people will experience significant decreases in water resources due to climate change (McCarthy et al. 2001).

To investigate how people's livelihoods are susceptible to climate change and how they might adapt to changing environmental conditions, studies have increasingly employed analytical approaches that focus on the vulnerability of a community or society (Burton et al. 2002; Turner et al. 2003; Lim and Spanger-Siegfried 2005; Füssel and Klein 2006). The broad purpose of these vulnerability approaches, particularly the "bottom-up" analyses, is to document the ways in which communities are sensitive to changing conditions and the ways in which they currently deal with the changes, in order to identify needs and practical opportunities for future adaptation (Schröter et al. 2005; Sutherland et al. 2005; Smit and Wandel 2006). Understanding the existing sensitivities and adaptation processes is seen as a useful (and perhaps necessary) basis for considering future exposures and adaptations. This paper reports on a study that employed a bottom-up approach to investigate the vulnerability of the community of Diaguitas in the Elqui Valley, in Chile's dry north-central region.

The IPCC notes numerous studies of climate change impacts on physical and ecological systems in Latin America, including dry regions, but there have been very few analyses of the vulnerabilities of communities and the practical adaptation options available at a local level (IPCC 2007). Among the research gaps identified by the IPCC are "limited studies on the economic impacts of current and future climate variability and change", "restricted studies on the impacts of climate change on societies", and limiting examination of means of "reducing vulnerability and/or increasing adaptive capacity" (Magrin et al. 2007). This paper addresses these gaps by analyzing how the socio-economy in this dry region is affected by variable climatic conditions, and how people and institutions have adapted, as a basis for assessing community vulnerability and adaptive capacity in the face of a changing climate.

Dryland ecosystems are susceptible to even small changes in the water cycle (Kalthoft et al. 2006), and the Elqui Valley has been referred to as one of the most sensitive areas to water variability in South America (Downing et al. 1994). The climate, with an inland annual average precipitation of approximately 110 mm, is strongly influenced by ENSO, with several years of dry conditions (La Niña) followed by periods of intense rainfall events (El Niño). Rainfall and runoff are very low and variable, and drought is common. The valley's economy is largely based on irrigation-dependent agriculture. The valley is experiencing a rapid increase in large-scale commercial operations, and small-scale farms have decreased in number and size. Agricultural products include table grapes for export, *pisco* grapes (for Chilean brandy) and smaller amounts of avocado and citrus. Irrigation water is derived predominantly from the Elqui River, which is fed by glacier and snow melt in the Andes.

This paper characterizes the vulnerability of the community of Diaguitas, in the Elqui Valley, to water and climate-related stresses, within the broader context of changing physical, economic, political and social conditions. The case study is guided by a model that conceptualizes vulnerability of a community to be related to the community's exposure to physical and other conditions to which it is sensitive as well to the community's capacity to adapt to these conditions. The paper provides a review of concepts as a basis for outlining the approach taken to assess vulnerability in the case study. The approach documents the multiple exposures and sensitivities faced by the community, and identifies their ability to adapt to these exposures, currently, and in light of expected future changes in climate.

## 2 Vulnerability concepts and frameworks

The concept of vulnerability has developed in various fields and contexts, including natural hazards (Burton et al. 1978; Cutter 1996; Cutter et al. 2003), ecology (Holling 1973; Folke et al. 2002) political ecology (Blaikie et al. 1994; Wisner et al. 2004), food security (Sen 1981; Watts and Bohle 1993; Dilley and Boudreau 2001) sustainable livelihoods (Chamber and Conway 1992; Turner et al. 2003) and environmental change (Liverman 1994). In the climate change field, vulnerability has emerged as a key concept relating to adaptation in both the scholarly and policy debates. The United Nations Framework Convention on Climate Change (UNFCCC; Article 4.4, 1992) explicitly commits developed countries to assist developing countries "that are particularly vulnerable to the adverse effects of climate change." Action on adaptation has increasingly moved from attempts to measure levels or relative scales of vulnerability to attempts to outline the processes underlying vulnerability, and to identify opportunities to reduce it by promoting adaptation. The concept of vulnerability is now widely used to characterize and understand the implications of climate change at the community level (Leichenko and O'Brien 2002; Vasquez-Leon et al. 2003; Adger 2006; Füssel and Klein 2006; Smit and Wandel 2006).

Interpretations of the concept of vulnerability vary. In many climate change impact studies, vulnerability has been characterized in terms of physical stimuli and their impacts or residual effects. This view of vulnerability focuses on the nature and distribution of a hazardous condition as it affects human occupancy and the degree of loss associated with the occurrence of a particular event (Cutter 1996; Brooks 2003).

Another view of vulnerability focuses on the pre-existing state of a social system or community that renders it susceptible to harm. This interpretation highlights the conditions and processes that influence a society's exposure to stimuli and its ability to deal with hazards (Downing 2003; Polsky et al. 2003; Kasperson and Kasperson 2001). Attributes of social systems that can increase (or decrease) vulnerability include marginalization, inequity, presence and strength of institutions, food and resource entitlements, economics, and politics (Adger 2000; Pelling 2002; Smit and Pilifosova 2003).

These concepts are now commonly employed in vulnerability and adaptation work in the field of climate change (Handmer et al. 1999; Kelly and Adger 2000; Leichenko and O'Brien 2002; Adger 2003; Ford and Smit 2004; Wisner et al. 2004; Belliveau et al. 2006; Füssel and Klein 2006). This approach to vulnerability as a property of human systems subject to stresses requires an understanding of the human use of and access to resources, which includes consideration of an individual's or society's sensitivities and abilities to adapt to change. A commonly adopted notion of vulnerability in the climate change field refers to "the degree to which a system is susceptible to, or unable to cope with, adverse effects of climate change, including climate variability and extremes" (Smit et al. 2000; IPCC 2001).

The vulnerability of a human system such as a community is generally conceptualized as a function of the community's exposure and/or sensitivity to changing conditions and the community's adaptive capacity to deal with those conditions. This broad conceptualization of vulnerability to climate change is summarized formally as (after Smit and Pilifosova 2003):

$$V_{ist} = f\,(ES_{ist},\ AC_{ist})$$

Where: $\mathrm{V}_{\mathrm{ist}}$ = Vulnerability of system $i$ to climatic stimulus $s$ in time $t$; $\mathrm{ES}_{\mathrm{ist}}$ = Exposure-Sensitivity of $i$ to $s$ in $t$; $\mathrm{AC}_{\mathrm{ist}}$ = Adaptive Capacity of $i$ to deal with $s$ in $t$. This formulation provides the basis for explaining the approach employed in this study, and it makes explicit the logical structure that guides the empirical work. The model indicates that vulnerability (V) is a property of a system ($i$, in this case, a community), and varies from community to community, varies according to the type (or types) of climatic stimulus, and varies over time (it is dynamic). The two key components of vulnerability are the manner and degree to which the community is exposed to conditions or stimuli to which it is sensitive, and the capacity of the community to adapt, both of which are also specific to communities, stimuli and time periods. This conceptualization of vulnerability is broadly consistent with several other models of human-environment interactions and vulnerability (Brooks 2003; Polsky et al. 2003; Turner et al. 2003; Keskitalo 2004; Lim and Spanger-Siegfried 2005; Luers 2005; Adger 2006).

Exposure-sensitivity reflects the interaction of the characteristics of the system (sometimes referred to as occupancy characteristics or sensitivity) and the climate conditions to which the system is sensitive (sometimes referred to as external stimuli, stress or hazard) (Downing 2003; Smit and Wandel 2006). For example, a community whose livelihood is highly dependent on water resources is more exposed and sensitive to drought than a community facing equivalent moisture conditions but having livelihoods that do not depend on the availability of water. Local conditions that influence exposure-sensitivity (e.g., settlement location and types, livelihoods, land-uses, etc.) reflect the broader social, economic, cultural, political and environmental conditions (Adger and Kelly 1999; Smit and Wandel 2006).

Adaptive Capacity refers to a system's potential or ability to adjust to exposures in order to moderate damages, take advantage of opportunities or cope with effects (Smit et al. 2000; Yohe and Tol 2002; Füssel and Klein 2006; Adger et al. 2007). Adaptive capacity varies between countries, communities, among social groups and individuals, and over time. The adaptive capacity of a community is a dynamic function of local processes and conditions which, in turn, are influenced by broader socio-economic and political processes. Adaptive capacity is influenced by assets and access to resources such as economic wealth, technology, information, infrastructure, knowledge and skills, social capital and institutions (Watts and Bohle 1993; Adger 2003; Klein and Smith 2003; Smit and Wandel 2006).

This conceptualization of vulnerability is a partial one, designed for climate change applications; hence, the stimuli refer mostly to climatic conditions. Yet a community's exposure-sensitivity and adaptive capacity to climate change cannot be understood independently of the various other forces which affect the community and to which it adapts. The effects of changing climate conditions are felt synergistically with the effects of changing economic, political, social, cultural and technological conditions (Adger and Kelly 1999; Kasperson and Kasperson 2001; Turner et al. 2003; Füssel and Klein 2006; Tschakert 2007; Westerhoff and Smit 2008). Research on practical climate adaptation has shown that adaptations are rarely to climate change alone (hence "double exposure" and "multiple exposure"), and adaptations are invariably undertaken as part of ongoing risk management, resource management, or development strategies (hence "mainstreaming") (Huq et al. 2003; Thomalla et al. 2005; Belliveau et al. 2006). This conceptual foundation guides the case study of the Elqui Valley.

## 3 Analytical approaches

Conventional climate change impact studies start with scenarios of future climate change (typically temperature norms), model physical and biological effects, sometimes estimate economic impacts, assume either no adaptation or hypothetical adaptations, to calculate a "net" or "residual" impact. These "top-down" or starting at "end point" studies serve the central purpose of estimating impacts of specified changes in climate, to address the question of "dangerous" in the UNFCCC (Brooks 2003; O'Brien et al. 2004; Füssel and Klein 2006; Smit and Wandel 2006; Polsky et al. 2007). They do not focus on the socio-economic systems' sensitivities, nor the processes by which these systems experience and deal with changes in conditions.

The vulnerability or "bottom-up" or "starting point" approach has a direct practical focus on adaptation. It aims to identify (rather than assume) the climatic conditions to which a community is sensitive. It recognizes the role of other forces that interact with climate, it identifies the actual types of adaptive management that are operational and feasible in the community and what facilitates or constrains them, and it employs this characterization of the community's vulnerability as the basis for assessing both the risks and the adaptation prospects under a changing climate (Jones 2001; Lim and Spanger-Siegfried 2005; Smit and Wandel 2006; Polsky et al. 2007).

Adaptations, or particular adjustments in a system to better cope with external stress, are manifestations of adaptive capacity. There are many forms of adaptations including anticipatory or reactive, autonomous or planned, local or widespread, and technological, behavioural, financial, institutional and/or informational (Smit et al. 2000; Adger et al. 2007). Early assessments of adaptation and climate change treated adaptation strategies as rather discrete measures, considered in light of scenarios of future climate (Brooks 2003; Füssel and Klein 2006). Recent analysis of adaptation processes have shown that actions to adapt to climate risks most commonly represent modifications of existing resource management, risk management or sustainable development initiatives (Burton et al. 2002; Davidson et al. 2003; Huq and Reid 2004; Smit and Wandel 2006). Integrating adaptive strategies with sustainable development and livelihood initiatives is seen as a way to address immediate vulnerabilities and to improve the ability to deal with future exposures in light of climate change (Nelson et al. 2002; IISD 2003; IUCN 2004).

The approach used in this Chilean study was guided by the preceding perspectives on vulnerability, which have been used in a growing number of vulnerability and adaptation assessments around the world (Adger 1999; Vasquez-Leon et al. 2003; Ford et al. 2006; Sutherland et al. 2005; Belliveau et al. 2006; Crabbe and Robin 2006). The analysis begins with the community as the starting point, to identify how the community is currently exposed and sensitive, and in what ways its capacity to adapt is enhanced and constrained. This involves identifying and documenting the nature of past and current exposures faced by the community (what has affected them and how and why), the adaptive strategies they have employed, and how this reflects their capacity to adapt. Collection of data on these conditions and processes involves ethnographic methods to gain insights from community members plus compilation of information from physical evidence, instrument records and other documents.

Based on the current vulnerability, the second phase examines how expected future climate change will alter the nature of the identified exposures, and in what ways the community has capacity to deal with these changes (Smit and Wandel 2006). Future exposures relate to conditions which are expected to represent risks or opportunities to the community, both those identified by the community and potential conditions (such as those from climate scenarios) that may not yet be realized or problematic to the community. Assessment of future adaptive capacity is based on insights from past and current adaptations and from expected changes in the resources and assets that facilitate or constrain adaptation.

## 4 Case study

### 4.1 Study area

A summary of the physical and socio-economic conditions of the region provides a context for the vulnerability case study. The Elqui Valley is in Chile's north-central Fourth Region, which is bounded by the Atacama Desert to the north, the Andes to the east, the fertile Central Valley to the south, and the Pacific Ocean to the west (Fig. 1). This region is characterized by an arid climate. The Elqui valley is one of a series of transverse valleys running east–west from the Andes to the Pacific Ocean and covers 9 657 km$^2$.

The valley is narrow with steep slopes consisting of thin, dry, sandy soils and sparsely distributed steppe vegetation. The basin rises from sea level to 4,800 m asl in

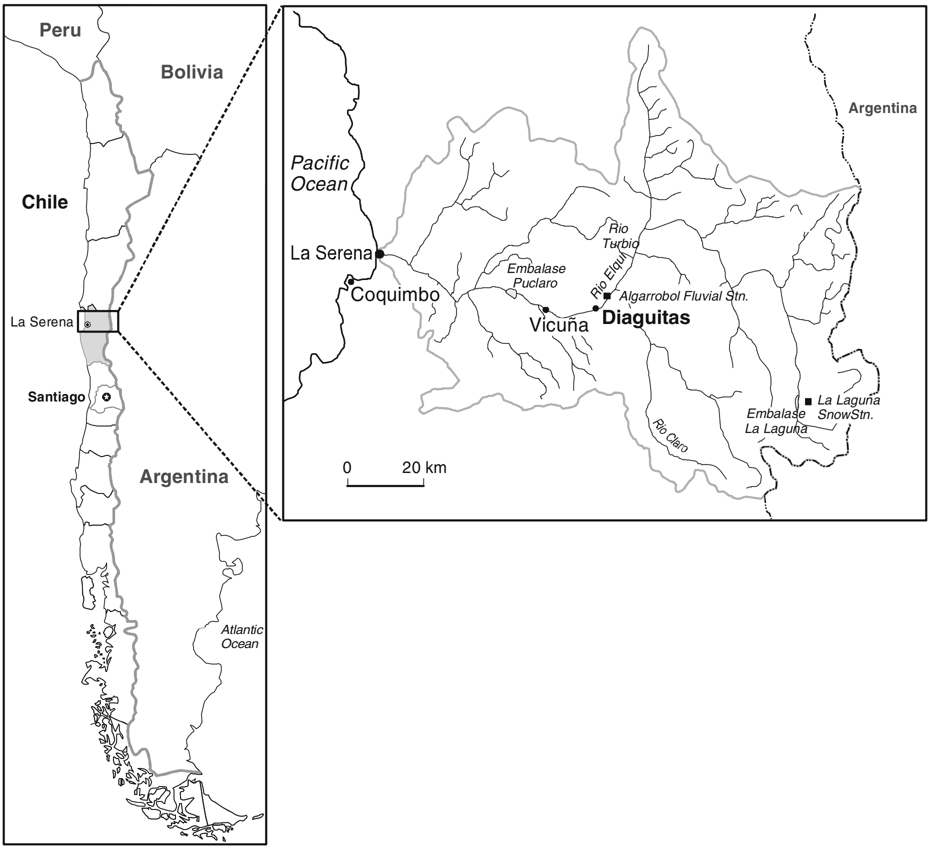


**Fig. 1** Location of the Elqui River Basin

less than 150 km. Snow and ice accumulate in the high mountains and feed the basin's rivers. Annual rainfall in the Elqui Valley is very low, approximately 100 mm/year, although this varies from year to year (Fig. 2) and through the valley, with an altitudinal gradient (approximately 83 mm at sea level to 200 mm at 3,750 masl). The majority of precipitation falls between May and August leaving the remaining months extremely dry. Preliminary field studies showed that communities in the Elqui Valley were sensitive to variations in moisture. Simple linear regression over time indicated a statistically significant (95% confidence) decrease in annual precipitation at both Vicuña and La Serena ($R^2$ values of 0.103 and 0.076 respectively) over the period of available instrumental record.

The Elqui River basin is exposed to the El Niño Southern Oscillation (ENSO) phenomena, and experiences oscillatory periods of long and persistent dry periods (La Niña) and intense, but short, precipitation events (El Niño). ENSO events occur irregularly but typically every 3 to 6 years. Table 1 illustrates average annual precipitation values at Vicuña for years with 6 months or longer of El Niño and La Niña influence, respectively, from 1950 to 2000. Notwithstanding the coarseness of the analysis and relatively high within group variation, annual rainfall varies significantly between El Niño, La Niña and non-ENSO years (analysis of variance, 95% confidence). El Niño years tend to have higher annual rainfall (mean 133.9 mm) than La Niña years (mean 68.3 mm) (Table 1). Annual precipitation has approached or exceeded double the mean annual values during five of the 14 El Niño-influenced years from 1950 to 2000.

The communities in the valley are dependent on river water. The Elqui River has two main tributaries, both of which originate in the high Andes; the Turbio River originates in the high Andes in the northeastern part of the basin, and the Claro River which drains the southeast. Diaguitas is downstream from their confluence.

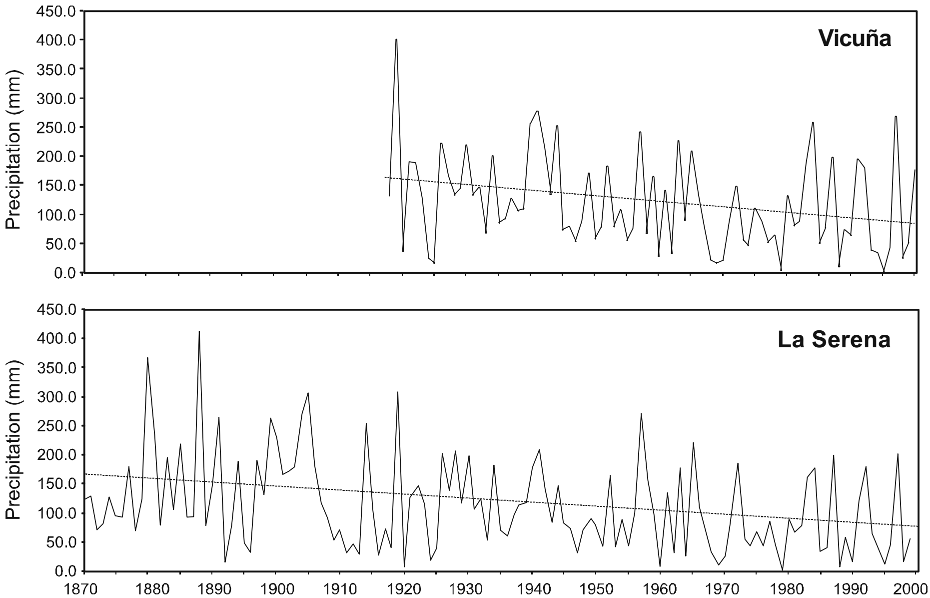


**Fig. 2** Annual precipitation for *La Serena* (1869–1999) and *Vicuña* (1918–1999)

**Table 1** ENSO effect and annual precipitation at Vicuña, 1950–2000

| | Precipitation (mm) | | | |
|---|---|---|---|---|
| | No. of years | Mean[a] | Std. dev. | Range |
| ENSO neutral year | 21 | 91.5 | 75.2 | 1.3–258.5 |
| El Niño years | 16 | 133.9 | 80.7 | 33.9–269.5 |
| La Niña years | 14 | 68.3 | 26.5 | 20.5–110.7 |
| All years | 51 | 98.4 | 71.2 | 1.3–269.5 |

[a]Between group variation in annual precipitation is statistically significant at the 95% confidence level

The Elqui River is characterized by high inter- and intra-annual discharge variability (Fig. 3). Flows at Algarrobal fluvial station, just upstream from Diaguitas, range from 2.4 to 33 $m^2/s$ throughout the year (Cepeda et al. 2004). Even though precipitation at Vicuña and La Serena has tended to decrease over recent decades, river discharge has not shown a corresponding trend (Fig. 3). The main source of the Elqui River is snow and ice melt, and discharge closely reflects snowfall in the High Andes portions of the basin (Fig. 3). Snowfall at higher elevations has not decreased in recent decades. River discharge is also expected to be related to increasing ablation of snow and/or ice associated with higher temperatures in the Andes (Strauch et al. 2006).

People in Diaguitas are also exposed to changes in Chile's political economy. The stresses on vulnerability emanate from economic and institutional conditions as well as from physical conditions. Chile is one of Latin America's most economically developed countries (World Bank 2004). Since the time of the military government (1973–1990) Chile's economy has been market-oriented and characterized by a high level of foreign trade. Chile's agribusiness has emerged as one of the country's major export sectors. Chile's broad diversity in environmental conditions allows for the cultivation of a variety of fruits and vegetables, and in recent decades the fresh

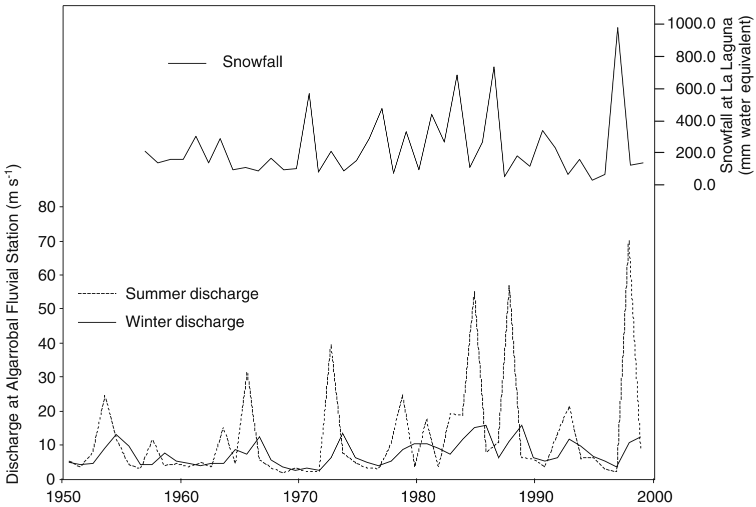


**Fig. 3** Summer and winter Elqui River discharge at Algarrobal station and snowfall at La Laguna station

fruit industry has grown considerably. Between 1980 and 2004, fresh fruit exports grew from US$168 million to US$1.9 billion, an 11-fold expansion over 24 years, and Chile now accounts for almost half of the Southern Hemisphere's exports of grapes, kiwifruit, apples and pears (ProChile 2005). The expansion of agri-business is heavily dependent on irrigation, which now accounts for 85% of consumptive water use in the country (Hearne and Donoso 2005). Economic development and resource use in the Elqui River basin reflect these national trends.

In this dryland region, where the Elqui River is the prime moisture source, local farmers have seen substantial growth in commercial agriculture operations. Sprawling irrigated vineyards and plantations now cover nearly every accessible portion of the valley floor and are rapidly expanding up the mountainsides. Multi-national agricultural companies have had an increasing presence in the Valley over the past 15 years. Most agricultural activities in the basin are related to fruit-production, particularly table grapes, citrus fruits and avocados for export, and grapes for *pisco* (brandy) production. These production systems are highly dependent on the discharge of (and hence exposed-sensitive to) the Elqui River for irrigation. Water from the Elqui River is diverted into irrigation canals which then weave through communities and make water available for use by owners of water rights.

Under the Chilean Constitution, water resources are defined as a 'National Good of Public Use' because they are essential for life, economic development, social objectives and environmental requirements (Productivity Commission 2003). Therefore, the state has the responsibility to regulate water use in a manner that meets these objectives (Productivity Commission 2003). Chile uses a market-oriented approach to allocate water resources under the Water Code of 1981 (Donoso 2006). Markets in water rights are employed with the intent to optimize the allocation and use of scarce water resources, under the assumptions that market pricing forces the highest value use of water, private property rights promote individual choice, and that the market is more politically neutral than the state in resource allocation (Haddad 2000; Budds 2004).

The Water Code is the principal legislation governing the management of water resources. The *Direccion General de Aguas* (DGA), a government agency within the Ministry of Public Works, grants private water rights and plays the central role in the management and use of water resources. Water rights, which are not tied to particular parcels of land, are private rights of use to a public good (water) and, if available, are granted with no charge; in the case of simultaneous competing requests, water rights are auctioned and granted to the highest bid. Once acquired, water rights have the same legal protection as any other private good, and can be freely traded, mortgaged or transferred (Budds 2004). Legally all rights are specified in volumetric terms (e.g. liter/second). However, due to traditional practices and the variability and uncertainty of flows, rights are often expressed as a proportion of flow (Bauer 1997; Productivity Commission 2003).

The *Direccion de Obras Hidraulicas* (DOH), another government agency within the Ministry of Public Works, is responsible for the construction and maintenance of water infrastructure projects, inclusive of irrigation and rainwater drainage structures. The DGA exercises broad authority over water resource management, while much of the basin-level management and supervision over river flows is under the authority of the *Junta de Vigilancia* (JDV). The JDV administers and distributes water from natural water courses to owners of water rights in a basin or sections of a basin. The JDV provides supervision over user associations sharing common water resources such as a particular irrigation canal within a basin (*asociaciones de canalistas* and *comunidades de aguas*). Much of the water management is informal, and, at the local level, there is considerable autonomy and variance from official allocations.

Potable water for household use in rural areas of the Elqui Valley is managed by *Comites de Agua Potable Rurales* (APR). Groundwater is pumped, treated and distributed to homes and industry. APRs are private, autonomous services providing basic potable water to small towns and communities that have a relatively high population density. Under the National Program of Rural Potable Water headed by the DOH, APRs are provided with the basic infrastructure and training to operate the machinery and obtain proper water samples for quality analysis.

Diaguitas (population approximately 700) is located 80 km from the coast at an elevation of 687 m asl, (see Fig. 1). Diaguitas is adjacent to the Elqui River at the base of the very steep hill, Cerro Mamalluca (2,219 m asl). Vineyards of three large export agricultural companies blanket the valley and hillsides of the community. These companies provide the main source of employment. Prior to the arrival of the companies, residents relied on the productivity of their *huertos* (gardens/small farms). However, small farmers can no longer compete with the low supermarket prices, nor do they have access to export markets, and often can not refuse the salaries and high prices they are offered from the agricultural companies for their land and/or water rights. Effectively, small farmers have few options but to work for the agricultural companies. There is also a small group of goat herders in the community who traditionally have grazed their livestock in a migratory fashion.

Most businesses and residents are either directly or indirectly dependent on water resources to sustain their livelihoods, either through employment from the agricultural companies (who require irrigation water for successful production and operation), through their own production of crops, to sustain vegetation and water sources for livestock, and for consumption of safe drinking water. Water is a key exposure, and the community's livelihoods and well-being are sensitive to effects of variations in the climate and water regimes, particularly extreme conditions, as well as to the evolving economic, social and institutional conditions.

### 4.2 Case study approach and methods

The objective of the case study is to empirically identify (rather than assume a priori) the factors and processes that affect this community and that characterize the community's vulnerability, as per the model outlined in Section 2. This involves documenting the conditions that have had an effect on the livelihoods and lives of residents and businesses, tracing the multiple forces and processes that contribute to the community's sensitivities, characterizing the ways in which the community has coped with or adapted to stresses, and assessing the constraints and opportunities for adapting to future changes in conditions. This type of research, which starts with assessing current vulnerability and is sometimes called "community-based" (Downing and Patwardhan 2005; Sutherland et al. 2005; Belliveau et al. 2006) is necessarily participatory, as it depends, in part, on collecting data on exposures and adaptive strategies and constraints from community residents. Semi-structured interviews with a sample of 48 community representatives and three focus group sessions provided data on the conditions (exposure-sensitivities and adaptations) that were pertinent to the community. These data were complemented by instrumental records, direct observation and documentation, administrative and historical documents, and scientific projections to characterize current and future vulnerabilities.

The field research team included two Chilean colleagues familiar with the region and Diaguitas. Establishing trust and credibility is essential for this kind of participatory research, especially in communities (like in the Elqui Valley) that have been subject to previous field research (Wallersetin 1999). By living in the community, the researchers built rapport, familiarity, and a sense of commitment with the community. It also provided opportunities to observe *huertos*, vineyards, irrigation systems and community livelihoods, experience events and social and economic interactions, and ground-truth statements given by respondents.

Of the 48 semi-structured interviews, 26 interviews were conducted with community residents and 22 were with representatives of institutions involved in water management and use. These institutional interviews were important as institutions can play a significant role in improving or hindering a system's vulnerability by facilitating or constraining adaptation to social and environmental change especially with respect to water resources. The institutional interviews were tailored towards the interests, responsibilities and roles of the institutions as they related to the community-identified exposures and adaptive strategies.

Semi-structured interviews allow for issues of interest (in this case, exposure-sensitivities, adaptations and adaptive capacity) to be targeted systematically, while allowing unbiased responses and reporting of personal experience. A common structure was used to guide the interviews and two focus groups (Table 2). The guide was designed to allow respondents to identify items relevant to them, to minimize researcher influence through prompting, to encourage elaboration of experiences and insights, and to check for information in key areas. The interviews and focus

**Table 2** Checklist of topics for semi-structured interviews and focus groups

| Key theme | Examples of issues covered |
|---|---|
| Background information | Livelihood<br>Length of time in Diaguitas<br>Water uses |
| Current exposure-sensitivities | Conditions that have been problematic regarding:<br>Social, economic, biophysical<br>Water and climate<br>When: past and/or present<br>To whom (individuals, community, producers, water managers, institutions)<br>When and how |
| Current adaptive strategies | How exposures are managed<br>Who (individuals, community, institutions, etc.) facilitates adaptation<br>What facilitates and constrains adaptive strategies |
| Future conditions | Based on previously identified exposures, would projected changes in e.g. land-use, economy, climate and water resources be problematic?<br>Affect individuals, community, producers, water managers, institutions?<br>How would individuals, community, producers, water managers, institutions manage these changes? |

groups generated the documentation on community-relevant exposures and adaptive strategies.

Purposive snowball sampling (Hay 2000) was used to identify interviewees. The sample of residents included men and women, small farmers, commercial agricultural companies, employees, goat herders, retired residents, small business owners, permanent, newly arrived and temporary residents, members of community clubs and water managers. The sample of institutional representatives covered the municipality, the region and various institutions, particularly those involved in the water sector such as the APR, DOH, DGA, JDV and *asociaciones de canalistas*.

The focus groups were designed as a cross-check on the interviews to consider processes affecting vulnerabilities beyond individual households. The first focus group consisted of a group of community key informants; the second focus group was conducted with the *Club de Adultos Mayor* (Elders Club) and the third with students from the local school. Each of the three focus groups consisted of between six and twelve participants who had not been interviewed, and was selected on a semi-structured, random basis.

## 5 Current vulnerability

### 5.1 Current exposure-sensitivities

The community has had to deal with a variety of interconnected environmental and socio-economic stresses. The multiple exposures, for the most part, were related (directly or indirectly) to water resources, but they were also related to the growth of the agricultural companies. In general, the exposures to which Diaguitas is particularly sensitive stem from four main inter-related factors: global climatic phenomenon (especially ENSO), the physical landscape, international demand (fruit and wine), and national economic strategies (export-oriented). The analysis here focuses on vulnerabilities related to water and climate, although these are experienced through connections with other forces and processes. Figure 4 summarizes the main inter-related forces and processes, across scales, that characterize the vulnerability of people in Diaguitas.

#### *5.1.1 Debris flows and flooding*

The consequences of intense rainfall events were a dominant concern for the residents of Diaguitas, as they are very sensitive to these conditions. Episodes of heavy rains, or '*lluvias locas*' (crazy rains) tend to occur every few years, coinciding with El Niño conditions. Some community members feel that the rains have become much more intense in recent decades. Many indicated that rainfall used to be more moderate—it would rain for days but with less intensity. Carrasco et al. (2005) indicate that during the last decades of the twentieth century, the frequency of precipitation events decreased but their intensity increased in conjunction with more frequent and intense ENSO events since the mid 1970s.

Heavy rains lead to high river flows and temporary lagoons and contribute to erosion (Cepeda et al. 2004). Diaguitas is located at the base of sparsely vegetated

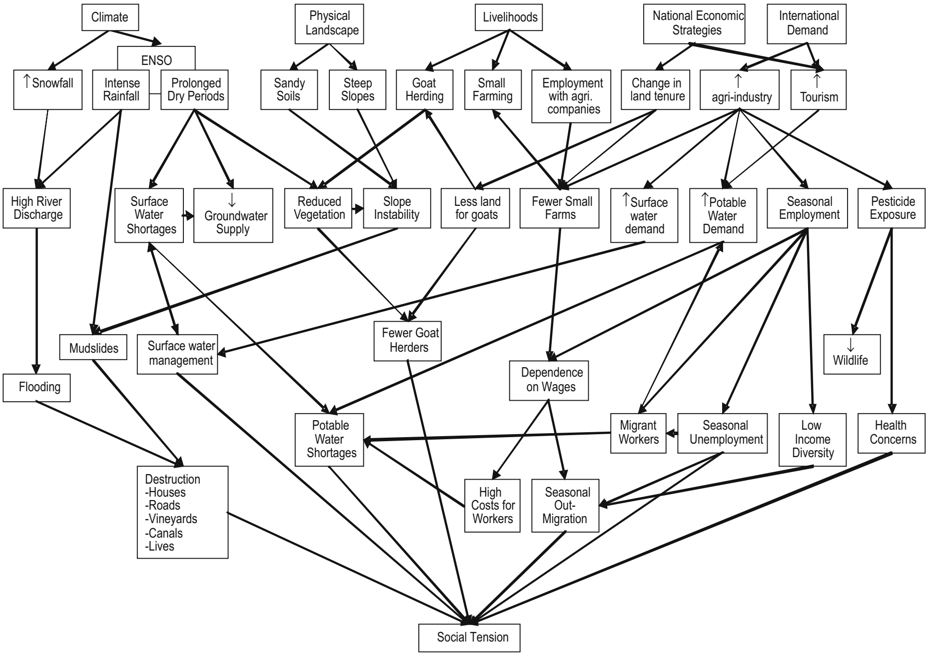


**Fig. 4** Main forces and processes related to the vulnerability of Diaguitas

slopes consisting of dry, sandy sediment, which are susceptible to debris flows when saturated. During the last decade, two major debris flows, in 1997 and 2004, affected the community when *lluvias locas* were experienced after prolonged dry periods. In 2004, more than 100 mm of rain fell in 6 h and triggered movement on the unstable slope. The resulting debris flows destroyed irrigation canals, caused river swells, blocked roads and made parts of the community inaccessible.

The physical landscape, steep and unstable slopes, sparse vegetation, and location of the community make Diaguitas susceptible to debris flows, but its exposure is compounded by human modifications of the slopes which have reduced the sparse vegetation via grazing and clearing and leveling for crops (Fig. 4). Land-use change, removal of natural vegetation and physical modification to the slopes contributes to slope failure (Gray and Sortir 1996). Goat herders promote erosion and slope instability by heavily grazing their animals on the sparse vegetation on the hillsides (Fig. 4). Though there are currently fewer goat herders than in the past, reduced access to the valley floor and lower slopes has contributed to more intensive grazing of the upper slopes. Commercial agricultural operations influence slope instability by removing natural vegetation and physical modification of the hillsides. Large areas of steep land have been cleared of vegetation, smoothed or terraced, and irrigated for vineyards, citrus and avocado plantations. Commercially planted vegetation does not stabilize the slopes in the way that the natural vegetation did, as the drip-irrigation fed roots of the vines are quite shallow and there is no canopy during the rainy season to protect the soil from the impact of the rain. In addition, agricultural soils tend to be more compacted and there is a decline in organic matter resulting from reliance on chemical fertilizers which also adds to their susceptibility to debris flows (Goudie 2001).

The recent and rapid expansion of commercial vineyards and the changes in land cover and land uses have modified drainage patterns. Older residents of the community noted that previously there were multiple *quebradas* (ephemeral creeks) which drained the slopes during periods of intense rainfall. Water would not accumulate and the energy of the water would be dispersed. With the modified landscape there are only one or two *quebradas* where all the water is forced to descend, increasing the force of the flow and moving more debris. Many respondents indicated that when the land was covered by natural vegetation and the surface was unmodified by humans, the energy of the debris flows was dissipated and less of a threat.

Residents are clearly sensitive to debris flows which are very destructive and threaten homes and lives. They cause damage to canals and vineyards and block roads and paths making it difficult to help other residents in more isolated parts of the community (Fig. 4). Residents have been hospitalized with injuries and hypothermia and some have been left homeless and forced to relocate or replace their homes.

### *5.1.2 Dry periods and natural vegetation*

Prolonged dry periods, typically coinciding with La Niña episodes, directly affect the natural vegetation on which goat herders rely (Fig. 4). During prolonged dry periods there is insufficient moisture for vegetation growth and the goats have insufficient feed over their usual grazing areas. People observe that precipitation is declining and that dry periods are longer.

There is evidence of declining average annual precipitation in the basin, most pronounced in the coastal area, in the order of 50% over the period 1900–2000 (Cepeda et al. 2004; Mall 2005; Kalthoft et al. 2006). Between 1915 and 2003 the Elqui Valley experienced 16 years of drought conditions (30–60 mm of precipitation) and 11 years of extreme drought conditions (less than 30 mm; Fiebig-Wittmaack and Perez Valdivia 2005). Consistent with community insights, data for the Elqui Valley (see Fig. 2) show that there has been a decrease in precipitation in the area (Cepeda et al. 2004; Carrasco et al. 2005; Kalthoft et al. 2006).

Dry periods were not perceived as a source of concern equally among the members of the community. The majority of Diaguitas' residents no longer rely directly on their own agricultural production since they have become dependent on wages from agricultural companies. The agricultural companies are not particularly sensitive to precipitation as they are more dependent on river discharge for irrigation than precipitation.

### *5.1.3 Irrigation water shortages*

Agriculture in the Elqui River basin relies on irrigation. Water is delivered to agriculturalists via a complex system of canals and gates, and water rights in Diaguitas are administered as a portion of the water in the canal. In real terms, this translates as a defined period of time during which owners of water rights who are located on a particular canal (*canalistas*) are entitled to the water in the canal and are allowed to open their canal gates to capture this flow. The system depends on the availability of sufficient water in the canals and cooperation among the *canalistas*. Since the water in the canals relies on gravity feed from higher points on the Elqui River, periods of low flow could lead to insufficient water in irrigation canals and thus have implications for the security of agricultural production. Agricultural companies and small landholders are very sensitive to river water supplies, and to the institutional arrangements and market forces that influence water rights and use.

The record of Elqui River discharge since 1950 (Fig. 3) indicates considerable inter-annual variability and some evidence of increased discharge since 1980. This availability of surface water has been one of the factors contributing to the expansion of irrigated production in the valley. Producers are clearly sensitive to both abundance and deficits in irrigation water supplies.

### *5.1.4 Access to potable water*

Potable water in Diaguitas primarily comes from ground water (Fig. 4). The community has a community well, two storage tanks and a local *Comite de Agua Potable Rural* (APR) to provide and distribute potable water to the community. The APR distributes potable water to residents who are billed monthly. Demand increases during the summer months due to temporary population increases and industrial and recreational potable water use. The packing departments of agricultural departments require potable water to prepare grapes for export. Migrant workers and tourists place additional pressure on the potable water supply, particularly as increasing wealth and tourism have led to more swimming pools (which are filled with potable water). In addition, supply decreases during the dry summer months when aquifer recharge is slower or non-existent. During times of higher demand in the summer, the potable water supply is frequently shut off by the APR for the entire community, including agri-business. Water is shut off to individual households by the APR if a resident fails to pay their bills, which is an issue particularly for pensioners and seasonal workers. A water bill can amount to approximately 25% of a seasonal worker's salary at times.

There are also private wells in existence in the valley, probably used for both potable and irrigation purposes. While there is clearly a sensitivity to ground water supplies, there is little documentation on the ground water hydrology. It is commonly accepted that precipitation is essentially irrelevant to groundwater, but information on the relationships with river discharge and draw-down recharge rates is not readily available.

### *5.1.5 Socio-economic exposure-sensitivities*

> "*then arrived the hand of the rich man and everything changed.*"—Resident of Diaguitas

Multi-national agricultural firms have grown in the Diaguitas area reflecting Chile's export-oriented economic strategies and the favourable local conditions (Fig. 4). The companies have created many employment opportunities, but they have also brought other changes and challenges to the community.

Residents have become less dependent on their own agricultural production, and dependency on employment (wage labour) has increased. Many residents of Diaguitas are small farmers who do not have the ability to compete with companies and super markets. Residents sought employment with the companies for income, and some sold their land and/or water rights to the companies. As one respondent stated, “the small farmer really doesn’t have a possibility”. Even those residents who have some land often grow little because of lack of time, lack of markets and the stigma of growing basic food crops. The water regulatory framework has also tended to work against small landholders due to inability to bid successfully and hoarding of non-consumptive rights (Donoso 2006). A large portion of the community is now dependent, directly or indirectly, on the agricultural industry to maintain their livelihoods. There are very few employment opportunities in other industry or service activities, education levels are very low among the adults, and most young adults have only ever worked in commercial agriculture, forcing some men to leave the community for months at a time to work in other areas. Wages are low and employment is typically seasonal, leaving even employed residents with limited income.

The agricultural companies have also attracted a steady seasonal influx of migrant workers. Some workers choose to settle permanently while others work on contract for out-sourcing companies. Some of the agricultural companies use out-sourcing to bring in workers who will work for less money than community residents. This process has created social tension and community segregation between the original residents and the newcomers (Fig. 4). The newcomers are blamed for bringing social problems to the community and there is a strong concern that the community’s identity is being lost. The changing economic and social conditions, particularly the reduction in livelihood opportunities, contribute to the susceptibility of the community to climate-related exposures and influence the adaptive strategies available to deal with the hazards.

## 5.2 Current adaptive strategies and capacity

“*Here in Chile we adapt to everything*”—Resident of Diaguitas

Several adaptation strategies are commonly adopted, with varying effectiveness, to cope with the problematic conditions. Adaptation strategies are evident at several levels of society, from the individual and household to community, municipal and regional institutions. Table 3 illustrates the main adaptations to climate-related exposure-sensitivities, distinguished according to scale (Individual and Community versus Institutions). Notwithstanding the claim of adaptability by the resident, strategies employed to deal with the exposure-sensitivities are rather limited. Many of them are reactionary, tending to address immediate consequences rather than the sources of the problems. These ‘band-aid-like’ solutions often leave the residents susceptible to future hazardous conditions.

### *5.2.1 Debris flows and flooding*

There are several adaptations taking place to help prepare for and cope with the consequences of intense rainfall. After the 2004 debris flow, large bowl-like structures were constructed by the regional *Direccion de Obras Hydraulicas* on the slope above the community to collect descending debris and retain water. These engineering works have been effective in managing the consequences of moderately intense rain events and associated modest flows, but many are nearly at capacity. This renders them ineffective to cumulative or large flows, and places the community at risk. Currently there is no responsibility taken for these structures as the DOH that

**Table 3** Community and institutional adaptations to climate-related exposure-sensitivities, Diaguitas

| Exposure-sensitivity | Individual and community | Institutions |
|---|---|---|
| Debris flows and flooding | Residents reinforce their doors, roofs and windows. | The Municipal Emergency Committee distributes a bulletin and broadcasts radio announcements reminding residents how to prepare for the winter/rain season. |
| | Residents stockpile extra food and batteries. | The DOH constructed two artificial channels to deflect debris/water away from the community. |
| | A 'Community Emergency Committee' established after the 1997 mudslide. It no longer exists. | The DOH constructed pool-like structures to collect debris/water that descends down the hills. |
| | Spontaneous solidarity to help neighbours in times of emergency by helping to remove debris, clean canals. | 'Shacks' were provided by the government to those that lost their homes. |
| Dry periods and natural vegetation | Goat herders migrate to areas with more vegetation | |
| Irrigation water shortages | An agricultural company has water rights on two canals, one for daily and the other for emergency. | The Junta de Vigilancia and/or the president of the canal are able to diminish the intake of the canals. |
| | Agricultural companies use efficient irrigation systems. | In drought emergencies the DGA is able to reduce all water use and seize water rights under orders of the President of Chile. |
| | An agricultural company sends an employee to check that canals are flowing on schedule. | Public funds are available by application to improve irrigation efficiency. |
| | Small farmers tend to accept circumstances/losses. | |
| | Few small farmers have storage ponds. | |
| Access to potable water | Residents keep barrels full of water for times when water is shut off. | The APR does not shut off residents' water right away, as there are months when people are jobless and unable to pay their bill. |
| | Some couples do not marry in order to receive a subsidy for single mothers to increase access to potable water. | Subsidies are available from the government to single mothers to pay for potable water. |

constructed the original capture areas does not have the responsibility to maintain them.

Two artificial channels were constructed by the DOH after the 2004 debris flows to divert water and debris away from the community and school. For the most part, these channels are narrow and simply dug into the loose sandy soil. The diversion channels have not yet been tested. However, the structures are deemed to be ineffective by residents and some regional engineers with the DOH on the grounds that the structures are not large enough to contain the large flows.

The regional emergency department, *Oficina Regional de Emergencia* (OREMI) is involved in planning for the prevention of and response to emergencies in the region. In recent years, OREMI has begun using the internet to obtain data on extreme weather forecasts and seismic activity. OREMI relays information on potential hazards such as debris flows and flooding to municipalities and emergency response organizations and thus allows for more timely actions. In response to the debris flow in 1997 the regional government built small 'shacks' for those who had lost their homes.

At the municipal level, prior to the beginning of the winter/rainy season, the Municipal Emergency Department distributes bulletins to households and conducts radio announcements to disseminate information on preparing for heavy rains. The bulletin and announcements remind residents to reinforce their roofs, windows and doors, remove debris from their yards and irrigation canals to avoid flooding, have supplies of food, water, batteries, and first aid materials, and be prepared to help neighbours.

In 1997, residents of Diaguitas created a Community Emergency Committee in response to a prolonged water shortage, an earthquake, and debris flows following heavy rains. Municipal and regional emergency departments and other institutions were slow to respond during these problematic conditions, and Diaguitas wanted to be better organized and prepared for future emergencies. However, due to a lack of resources (money, equipment) the committee could not function properly and no longer exists.

The technological and institutional adaptive strategies would appear to modestly (at best) reduce risks of future debris flows and flooding. At the level of households and local networks, residents employ a range of adaptive strategies. When heavy rains are anticipated, residents commonly reinforce their homes (windows, roofs and doors) and purchase extra food and batteries and clean canals. The *asociacion de canalistas* cleans canals and closes irrigation gates in order to reduce the risks that canals overflow and the walls of canal walls are damaged. However, individuals commonly accept that debris flows are part of living in Diaguitas and do not currently have a comprehensive anticipatory strategy to lessen their vulnerability, and may again need to rely on government-provided temporary housing (as was the case after the 1997 events).

### *5.2.2 Dry periods and natural vegetation*

During prolonged dry periods with low natural vegetation growth, goat herders have less access to fodder for their animals. Their adaptive strategy is to migrate well down the valley, even to the coast, where there is generally more moisture to support vegetation due to the fog and increased atmospheric humidity from the ocean. However, this is costly for herders because often they have to rent vehicles to transport their herds. If the herders do not migrate they risk losing many goats, their milk production will be very low, and their incomes and livelihood threatened.

### *5.2.3 Irrigation water shortages*

Variability in Elqui River discharge over the years has meant that Diaguitas has often experienced insecure irrigation water supplies. Agricultural companies have adapted by increasing water use efficiency, implementing off-stream storage facilities, and securing access to additional water rights (Table 3).

Increased water efficiency has been achieved in industrial agriculture through highly efficient drip-irrigation systems, and the implementation of concrete liners for secondary irrigation canals to minimize water loss through seepage. In addition, the agricultural companies have constructed large storage ponds which allow them to irrigate at times when needed for production, even when flows in the river and canal are low. These technologies reduce their susceptibility to periods of surface water scarcity. One agricultural company has also purchased water rights on two canals to ensure an extra supply of irrigation during extremely dry periods and to spread the risk of one particular canal having insufficient flow for irrigation. Agricultural companies have also sent employees to monitor usage along canals to ensure that individuals and other companies do not access more water than they are entitled to, thus increasing the chances that water will be in the canal when the company needs it.

At the community scale, during times of water shortages the *Junta de Vigilancia* or the *asociacion de canalistas*, have the discretion to lower the main canal gate and reduce the intake into the canal. During official drought emergencies, the *Direccion General de Aguas* has the authority to call for a reduction in all private water use (Hearne and Easter 1997). Official drought zones are declared by the president of Chile forcing farmers to use less water. In times of water shortages, owners of water rights share the shortage by each receiving less of the available water.

Small holder adaptations to surface water shortages are limited. Small producers use less efficient, traditional flood or furrow irrigation techniques. The lowering of the main canal gate during times of shortages means they have little or no irrigation water. While small farmers tend to accept the circumstances and associated potential losses, a few producers have small storage ponds for irrigation water. A program exists to assist individual farmers in improving the efficiency of their irrigation systems. Improvements could include cementing a portion of the canal, covering the canal, making a small reservoir and/or upgrading from furrow irrigation. After application, approval and inspection of the improvement project, the farmer may be refunded for 75% of incurred costs. However, it is beyond the capacity of most, if not all, small farmers to access these funds. Farmers do not have the resources to complete a computerized form, travel to the region's capital, pay a non-refundable application fee and fund the project itself. While this may be a technically appealing adaptation to climatic risks, when the economic and social factors are recognized, it is operationally infeasible. No farmer in Diaguitas has taken advantage of this program.

The water use rights and regulatory framework facilitate one facet of adaptation to variable water supplies. Donoso (2006) points out that markets for water rights are more actively traded in areas where water resources are scarce. The market allocation is efficient, but inequitable access, speculation and hoarding has allowed for monopolistic behaviour on the part of rights holders and powerful interests (Donoso 2006). The adaptive strategies relating to more efficient irrigation have a feedback to water supply exposures. With more efficient irrigation, less of the water drawn under a water right is returned to the river, reducing supplies to users downstream (Rosegrant and Gazmuri 1995). This type of feedback where an adaptation serves to alter an exposure-sensitivity is not uncommon (e.g. Belliveau et al. 2006; Westerhoff and Smit 2008). Furthermore, such situations may prompt changes in the institutional arrangements which fostered the original vulnerability. In response to reductions in return flows, due to water sales and efficiency gains, the Elqui River Water Users Association limited trades in upstream areas to farm-to-farmer transactions to retain all return flows in the basin (Rosegrant and Gazmuri 1995).

Occasional irrigation water shortages in Diaguitas have always existed. Larger producers are better able to adapt to the conditions due to greater economic and technological resources, and their ability to benefit from the institutional arrangements. However, they are still vulnerable to prolonged water shortages.

#### *5.2.4 Access to potable water*

Sensitivity to potable water is related to insufficient or unreliable supply at the community scale, and an inability to connect to the potable water system due to the location of a dwelling and/or inability to pay for water at the individual level. The community has become accustomed to periods when there is insufficient potable water supply, especially in the summer. Individuals adapt to supply insecurity by keeping barrels full of water. The fruit processing companies who use potable water for cleaning and packaging have had difficulty managing this problem, and often have to close down the packing department until the water is turned back on.

For those members of the community unable to connect to the potable water distribution system, the municipality delivers potable water. In the case of non-payment, the APR is generally sympathetic and lenient to those who can not always make their payments and often gives households several months to pay before shutting off the water. The government also provides subsidies to single mothers to help pay for potable water, a policy which has led to some couples not marrying in order to be eligible for these funds.

There appears to be no systematic, institutional set of procedures to deal with the recurring periods when potable water supplies are insufficient to meet demands in Diaguitas. The existing ad hoc arrangements by the APR, residents and companies would appear to ensure that the community remains sensitive to the limited and variable supplies of water in the valley.

## **6 Future vulnerability**

### 6.1 Future exposures

In the future, especially under climate change, several of the conditions to which Diaguitas is sensitive are likely to be exacerbated (Table 4). The capacity of the community to deal with these changing exposures relates to the opportunities and constraints evident in current adaptation processes, and how these might be moderated by changes in the society-economy and its institutions.

Key sources of projections under climate change are the IPCC (2001, 2007), Cepeda et al. (2004), and Souvignet et al. (2008). Under climate change the Elqui River Basin can expect to experience increased frequency and intensity of ENSO processes, resulting in intense rainfall events (El Niño) and more frequent and prolonged periods of drought (La Niña, Downing 1992; IPCC 2001, 2007; Cepeda et al. 2004). The cycle of prolonged dry periods followed by intense rainfall on the

**Table 4** Expected changes in climate-related conditions for Diaguitas

| Condition | Expected Change |
|---|---|
| El Niño | The frequency and intensity of El Niño is likely to increase as a result of climate change (IPCC 2001; Souvignet et al. 2008). Since the mid-1970s, the El Niño phenomenon has been more frequent and more persistent (Carrasco et al. 2005). |
| Rainfall | A decrease in average precipitation is predicted (IPCC 2007) by 30% by 2059 (Souvignet et al. 2008). In the past 100 years precipitation has decreased by 50% (Cepeda et al. 2004). |
| Drought conditions | Climate change may result in more frequent and prolonged droughts (Downing 1992; IPCC 2001; Cepeda et al. 2004; Souvignet et al. 2008). |
| Debris flows | An increase in El Niño events combined with changes in land use and the physical landscape has the potential to cause more debris flows. |
| Temperature | The north-central area of Chile can expect an increase in temperature (IPCC 2001, 2007) of approximately 2–4 degrees Celcius during the second decade of the 21st century (Cepeda et al. 2004). Higher temperatures and hence higher crop evaporative demand, mean a tendency towards an increase in irrigation demands (IPCC 2001). Increased temperatures will result in less snow accumulation in the High Andes as the 0 degree isotherm moves to higher altitudes and icing days are expected to decline by 70% by 2059 (Souvignet et al. 2008). |
| River discharge | Andean glaciers are predicted to recede (IPCC 2001, 2007; Souvignet et al. 2008). Increase in discharge is expected in the short/medium term due to increased snowfall, the melting of snow and glacier reserves (Cepeda et al. 2004) and discharge variability is expected to increase (Souvignet et al. 2008). In the long-term, as the reserves diminish and volume of melt decreases, flows will no longer be supported and will decline to below present levels (IPCC 2001). Less snow accumulation in the High Andes will result in lower summer discharge. |

poorly consolidated sandy soils triggers debris flows. In north-central Chile, these occurrences typically correlate with El Niño events (Sepulveda et al. 2006). Since the mid-1970s, El Niño episodes have become both more frequent and more persistent and this trend is expected to continue (Mata and Campos 2001).

Although El Niño brings isolated periods of abundant and intense rainfall, average precipitation has decreased in the Elqui River Basin (Fig. 2) and this trend could continue. Climate change scenarios (doubling of carbon dioxide concentration in the atmosphere relative to 1990 levels) have generally indicated a decrease in rainfall for this region (Downing 1992; CONAMA 1999, 2007; Cepeda et al. 2004; Christensen et al. 2007). A decrease in precipitation will directly affect farmers, commercial agriculture operations and goat herders who are very dependent on surface water. Further reductions in precipitation may force the remaining goat herders to abandon their livelihoods or migrate out of the region. A decrease in precipitation, together with changes in snow and ice supplies, will also affect groundwater recharge which is the source of potable water for Diaguitas.

The Elqui River is fed predominantly by snowmelt in the Andes. The current contribution of glaciers, notably El Tapado, is considered to be modest (Ginot et al. 2006). Under climate change it is expected that glaciers in this region will ablate (Mata and Campos 2001; Barnett et al. 2005) as glaciers in South America have receded dramatically in the past decades and many of them have disappeared (IPCC 2001). As temperatures rise in the region and glaciers recede, river discharge tends to increase, until the cumulative moisture source is depleted, when flows decline to levels sustained (if at all) by precipitation (snow or rain).

Rises in temperature and changes in the ENSO regime are likely to generate changes in the water cycle. There is evidence of elevation increase in the 0°C isotherm in this area (Carrasco et al. 2005). Currently, the 0°C isotherm is located around 2,500 m asl. Snow stations located at 2,800 m (El Indio) and 3,100 m (La Laguna) have recorded an average of 174.1 and 152.2 mm respectively of water column equivalent solid precipitation over the period 1981 to 1999. Currently, this winter precipitation maintains high summer flows.[1] A warming of 2°C to 4°C is expected by the second decade of the twenty-first century for this region (Downing 1992; Cepeda et al. 2004; CONAMA 2007), indicating that the 0°C isotherm may move into the altitudinal zone which currently serves to store winter precipitation for times when irrigation water is most needed. From the present to medium term, river discharge is expected to increase, and in the longer term river discharge is expected to decrease as snow and ice reserves diminish (IPCC 2001; Cepeda et al. 2004; Mall 2005). In addition, higher temperatures increase the water requirements for irrigation, in the order of 7% more irrigation water for each degree Celsius of temperature increase (Downing 1992). These expectations have major implications for the agricultural sector.

Currently, discharge levels are being sustained or increasing in the Elqui (Fig. 3). As surface water resources increase, further agricultural expansion tends to be encouraged, and demand increases. In the longer term, depletion of snow and ice reserves, coupled with increased periodicity and severity of drought, is likely to result in an overall reduction of the Elqui's flow to the point where current and future demands cannot be met. Figure 5 illustrates some of the potential effects of changes in climate in the shorter and longer terms.

The potable water situation in Diaguitas is also susceptible to future changes. Currently there is little information with respect to the interaction between groundwater and surface water, precipitation and groundwater recharge in the Elqui Valley. However, given decreases in precipitation and lower river discharge, it is expected that there would be less aquifer recharge, thus less potable water supply. Demands on potable water are already heavy, and sometimes cannot be met. Increases in demand from agribusiness, seasonal labour and tourism will be difficult to meet in a period of declining supply.

The effects of climate change on water, commercial activity and livelihoods in Diaguitas can be differentiated into shorter-term and longer-term (Fig. 5). In the shorter-term, an increase in temperature will accelerate snowmelt resulting in an increase in river discharge, the source of irrigation water, likely contributing to the continued expansion of agri-business in the valley. This would bring employment opportunities, but also more migrant workers, social stresses, and increased demands for irrigation and potable water. In the longer-term, temperature increases would ultimately deplete the snow and ice reserves, resulting in decreased river discharge and groundwater recharge and reductions in the supply of irrigation and potable water

[1] Simple linear regression analysis of snow accumulation in the High Andes at La Laguna snow station with summer discharge at El Algarrobal fluvial station, three km upstream of Diaguitas, over the period 1955–2000 indicated a statistically significant relationship between winter snowfall and summer discharge (99% confidence) with an $R^2$ of 0.889.

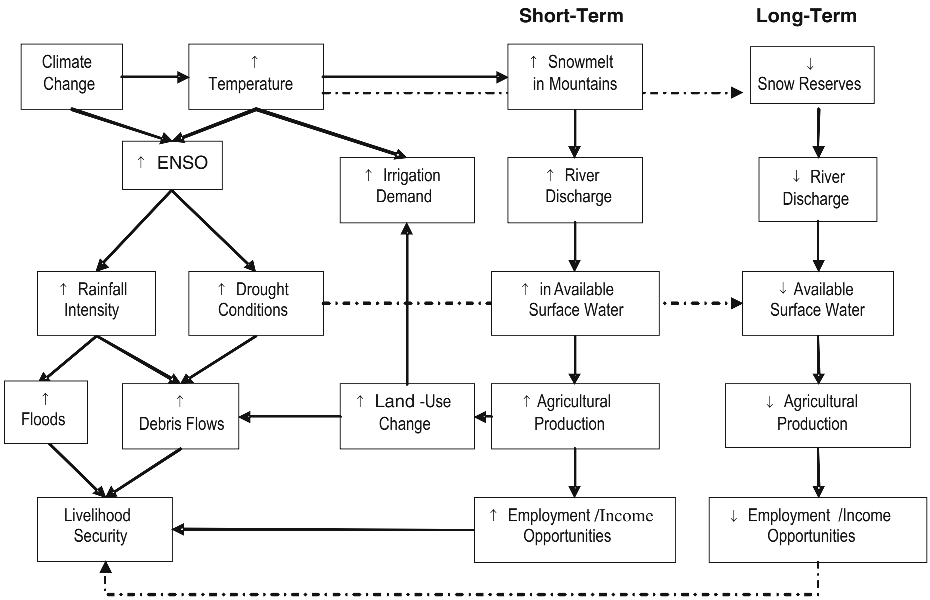


**Fig. 5** Selected effects of climate change on Diaguitas

along with increased water demands. The combination of higher water demands and reduced water supply would severely constrain agricultural operations at all scales and exacerbate existing stresses on the potable water supply. This would translate into a decrease in agricultural production and employment and lower security of potable water, thus affecting the industry, the regional economy and the livelihoods of the people of Diaguitas.

Countries, regions and communities with a large portion of the economy in agriculture face a significant exposure to climate change. All agricultural livelihoods in Diaguitas are exposed to climate change: goat herders may have insufficient natural vegetation for grazing their herds, small farmers will be affected by lower precipitation and less secure water supplies in canals, and agricultural companies will likely face inconsistent and insufficient surface water supplies for irrigation. Future water shortages would threaten the viability of the main sources of employment in the Elqui Valley, and put many livelihoods at risk.

## 6.2 Future adaptive capacity

Vulnerability of a community to future conditions is related both to future exposure-sensitivities and to the capacity of the community to adapt to those conditions. The ability to undertake adaptations is understood to be dependent on, or influenced by, a variety of conditions including effectiveness of institutions, access to financial and technological resources, information and knowledge, kinship, and social capital (Watts and Bohle 1993; Hamdy et al. 1998; Adger 1999; Handmer et al. 1999; Toth 1999; Kelly and Adger 2000; Smit and Pilifosova 2001; Wisner et al. 2004; Smit and

Wandel 2006). How and why people have adapted in the past provide indications about their potential to cope with changing conditions in the future.

Well-developed social institutions can help deal with climate-related risks (Adger and Kelly 1999; Adger 2000; Smit and Pilifosova 2001; Tol et al. 2004; Ivey et al. 2004; Naess et al. 2005). In the Elqui Valley, institutions from the national level to the community level provide a structure with the authority to manage both surface and potable water under changing climatic conditions. However, limitations in communication and coordination across levels and among institutions impede effective planning and response. High turnover rates of employees in the municipality and regional organizations also limit effectiveness due to deficits in knowledge and experience.

The institutional arrangements for allocating water resources would face problems of inequity, if not ineffectiveness, under diminished water supplies. Small farmers would be constrained in their efforts to maintain production and adapt to changes in surface water in the longer-term, particularly because of their inability to compete for more water rights when supplies are decreasing and the agricultural companies are struggling to meet their demands. Budds (2004) notes that the Chilean Water Code was formulated to benefit industrial-scale private sector development and requires substantial reforms if it is to address social equity.

It is generally considered that greater economic resources can contribute to adaptive capacity (Kates 2000; Smit and Pilifosova 2001). Many of the municipal, regional and water management agencies identified a lack of human and financial resources as major constraints on their capacity. Employees noted that tasks are often not completed due to lack of resources, and this was a key factor in the collapse of the community emergency committee and in the impracticality of the government program to improve irrigation efficiency.

Kinship and social cohesion among community members can contribute to adaptive capacity (Pelling 1997; Adger 2003). Diaguitas is experiencing segregation in the community and high social tension. Existing kinship ties and community identity are weakening with the dominance of agri-businesses and the influx of migrant workers. Any reduction in social tension would likely help adaptive capacity if for no other reason than freeing human resources for more productive investments. Pooling resources and ideas could allow for a coordinated approach to applying for funds to make improvements to the canals (increase efficiency of irrigation), and make improvements to the community to make it more attractive for tourism, a sector on which many in the community place hope. Tourism would serve to diversify the economic base and provide more secure livelihoods in order to better respond to changes outside their control, so long as tourism growth is not dependent on increased water supplies. An additional constraint to adaptive capacity in the community relates to leadership and organization. Community organizations were dismantled during the coup in Chile (1973), and there is still distrust among community members about participants' motives.

Greater access to information is expected to increase the likelihood and effectiveness of adaptations (Fankhauser and Tol 1997; Smit and Pilifosova 2001). Adaptive strategies are formulated within the confines of available information and resources. In order to make effective plans and policy for the future, it is important for decision makers in the communities, municipalities, regions, water management institutions and so on, to know the current and past changes of hydrologic and climatologic regimes and how the livelihoods of the people are sensitive to them. It is also important for decision makers to be aware of the social and economic conditions that influence adaptations, and the ways in which institutional arrangements facilitate or impede adaptation. In Diaguitas, there is limited knowledge about historical and expected climate and hydrological conditions, and how these combine with the land-use and economic changes to have implications for water resources and incomes. Without knowledge of the changing conditions and vulnerabilities, industry and institutions run the risk of not implementing anticipatory adaptations and/or reacting too late. Currently, institutions are planning predominantly for the short-term.

There is a general collective lack of awareness for possible future hazards and conditions. For example, most respondents did not believe that the average river flow could diminish, because the "mountains will always provide water". Respondents in the community and municipal, regional and water management institutions shared similar attitudes with respect to the future. Most of the respondents were not familiar with the term "climate change" and few were aware of the implications for their water resources and livelihoods. It was not surprising that little had been done to address risks associated with climate change. At the regional institutional and large-scale agricultural level, few respondents acknowledged climate change as a significant risk or concern to resources and/or industry, and few take any precautions with respect to future climate conditions.

These insights are generally consistent with those of Sepulveda et al. (2006) who looked at the geological hazard, climatic relationship and human response of debris flows in Chile. Sepulveda noted that there was no real consciousness in Chile about the hazard of debris flows and that people tend to forget about disasters quickly. The study also found that the attitude of authorities' (such as OREMI) to natural disasters in Chile is mostly reactive rather than preventative.

## 7 Conclusion

This paper characterized the nature of vulnerability in the dryland community of Diaguitas, in the Elqui Valley of Chile, in order to identify needs and prospects for adapting to climate change. The approach yielded information on the forces and processes contributing to current and future vulnerabilities in light of climate change. The study focused on water resources and water use by documenting the exposures and adaptive strategies of the community, and assessing the role of climate change in affecting the community vulnerability.

Vulnerability in water resource use was shown to reflect multiple exposures as changing physical and socio-economic conditions stress the community. A dominant risk to the community was rainfall abundance and intensity as this tends to trigger debris flows along the steep and unstable slopes. The community and regional water management agencies deal with these conditions via public education and some infrastructure adaptations. Surface water shortages were also found to be problematic for some sectors of the community. Goat herders are particularly affected by prolonged dry periods, as are small landholders. The majority of Diaguitas residents no longer directly rely on their own agricultural production, but are affected by water insecurity through the commercial agricultural operations. The agricultural companies, which rely on surface water, use highly efficient irrigation, purchase additional water rights, and have water storage systems to reduce their sensitivity to variations in supply. Potable water access has been problematic for the community (individuals and companies) during the summer months, due to a combination of high demand and slower recharge of the aquifer. There have been some adaptations to help cope with lack of accessibility, notably keeping small reserves and subsidies.

The water and climate-related exposures were important to the community, but they were experienced in the context of other non-water related stresses. Community members are concerned about the changes that have occurred to their livelihoods since the arrival of the agricultural companies. While the companies provide employment, the community now is dependent on a single industry for low-wage seasonal employment. The social tensions that have been created since the arrival of the companies and the influx of migrant workers have begun to deteriorate the kinship system and erode elements of social networks. The social tensions and segregation in the community have become a hindrance in the community's ability to organize, for example, to adapt to certain exposures or promote additional industries in the community to reduce its sensitivity. This is currently problematic and in the future it is likely to be a challenge to adapt and take advantage of opportunities. These conditions influence the community's occupance characteristics and sensitivities, and thereby affect future vulnerability of the community.

For the most part, residents of Diaguitas were more concerned with meeting the needs of daily life rather than with what could happen in the future, even if they had experienced the effects of droughts and debris flows in the past. Most respondents were particularly concerned with changing social conditions, such as employment and crime in the community, and there was less concern about changes in the climate and water resources and their implications for the future.

In the future, the community is vulnerable to changes in the hydrologic regime. An increase in frequency of El Niño years would likely instigate more debris flows due to the impact of the intense and abundant rainfall following the prolonged dry periods of La Niña, especially if the land-use changes continue to expose the slope surfaces. Temperature increases and changes in precipitation will affect the water cycle. In the short to medium term, river discharge is likely to increase, but as snow pack and glacier resources diminish, river discharge is likely to decrease. Such changes in water resources would have major implications for individuals, the commercial agricultural sector and water management institutions.

Several constraints to adaptation at the community and institutional level limit the capacity of Diaguitas and institutions to respond to future conditions associated with climate change. A lack of awareness of environmental changes and their implications for livelihoods and businesses, and a lack of concern for the future do not prompt precautionary planning. Adaptive responses tend to be reactive, and there is little evidence of planning for reduced water flows. The capacity of institutions and the community to adapt is limited by lack of information sharing, lack of financial or technological resources, and/or by limits in human capital. In particular, a weakened kinship and social organization in the community has likely decreased the capacity of the community to effectively deal with both current and future conditions.

This case study outlines the nature of a community's vulnerability to climate stresses in a dryland region of north-central Chile. Climatic conditions interact with the local physical environment and socio-political-economic systems to influence the vulnerability of the community. People in semi-arid regions currently exhibit vulnerability to existing climate conditions, many of which are expected to be intensified with climate change. It is noteworthy that this community was pre-occupied with stresses not directly related to climate change, yet which contribute to the vulnerability of the community. This study also shows that the coping ability of a community to deal with changes and risks will be greatly influenced by factors such as infrastructure, economic wealth, kinship, technology, information, and the role of institutions.

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