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ORIGINAL ARTICLE

Coping with climate-induced water stresses through time and space in the mountains of Southwest China

Yufang Su · Jianchu Xu · Andy Wilkes · Juliet Lu · Qiaohong Li · Yao Fu · Xing Ma · R. Edward Grumbine

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Abstract Southwest China's Yunnan province has been affected throughout history by climate-induced water stresses, with the 2009 drought as a recent example. To deal with such stresses, mountain farmers have developed many local coping strategies. This paper provides case studies of these coping mechanisms in three mountain communities in Baoshan Municipality, Yunnan province. To minimize water-related environmental and economic vulnerabilities, our results show that upland farmers employ strategies both individually and collectively, which vary according to agroecological zone, economics, and historical period. Climate change is also emerging as an ongoing environmental challenge. We explore China's options for introducing and implementing adaptation policies that link with farmer strategies to respond more effectively to water stresses induced by climate change and other forces.

Keywords Climate change adaptation · Mountain · Water stresses · Collective action · Yunnan province

Y. Su · J. Xu (✉) · A. Wilkes · J. Lu · Q. Li · X. Ma
World Agroforestry Centre, East Asia Node,
132 Lanhei Road, Heilongtan, Kunming 650204, China
e-mail: J.C.Xu@cgiar.org

Y. Su
Yunnan Academy of Social Sciences, Institute of Economics,
577 Huancheng West Road, Kunming 650034, China

J. Xu · Q. Li · Y. Fu · R. Edward Grumbine
Kunming Institute of Botany,
132 Lanhei Road, Heilongtan,
Kunming 650204, China

Introduction

Like the rest of rural China, Yunnan province has undergone massive socioeconomic transformations over the past half-century from state-planned centralized agricultural communes to a decentralized, market-driven economy. As a result of this transformation, the demand for water is increasing rapidly due to agricultural intensification and urbanization. Decentralization has also cut central government funding for rural infrastructure and institutional development. With about 64.8 % of the population (29.78 million) residing in rural areas (Information Office of the People's Government of Yunnan Province 2011) and largely dependent on agriculture for both cash income and subsistence needs, shifts in water availability and the lack of water management infrastructure have increasingly impacted production and local livelihoods in mountainous rural Yunnan.

Mountains contribute many water-related environmental services to downstream and adjacent regions (Viviroli et al. 2011; Xu et al. 2009), but suffer disproportionately high water stresses including drought, floods, erosion, and landslides (Xu and Daniel 2011). In fact, water-induced disasters in Yunnan, such as the 2009 drought, have increased over the past 50 years (He 2007). In Yunnan on average, farmlands impacted and/or destroyed by floods and droughts have been increasing (Fig. 1). Regional climate models predict that average surface temperatures in Yunnan will rise between 1 and 1.5 °C by 2050 (Xu et al. 2009). Yet, Yunnan's extremely complex topography means that even high-resolution climate models still cannot provide reliable regional projections. And while models attempt to predict future impacts of climate change, mountain people are already responding to climatic and socioeconomic stresses with a range of local practices though many of these remain

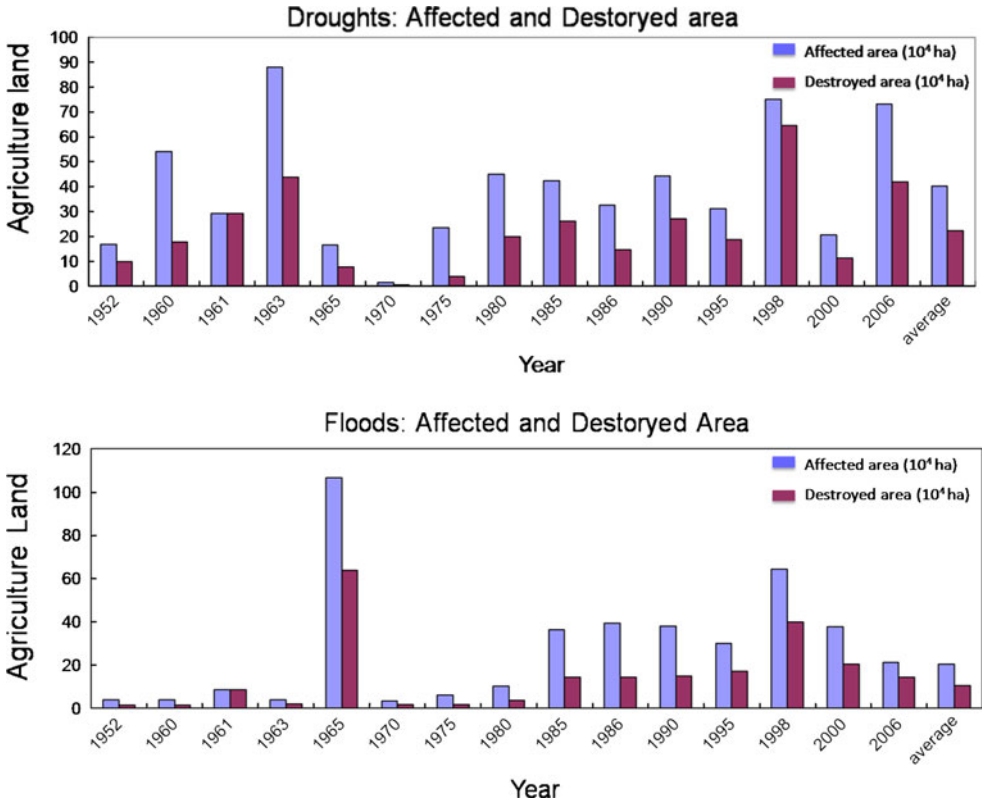

Fig. 1 Frequency of water-related natural disasters in Yunnan. *Source* He (2007)

poorly understood (Kloprogge and Van der Sluijs 2006; Byg and Salick 2009).

Present levels of uncertainty in climate impact assessment combine with various government development policies to place smallholder farmers in positions of vulnerability (Watts 2000). This demonstrates a strong need for planning based on the range of mountain peoples' adaptive responses. But so far in Yunnan, there has been little engagement with local people to learn about their experience in adapting to changing environmental and sociopolitical conditions. Integrated approaches to understanding historical adaptations and present vulnerabilities to water stress are needed in order to prepare for an increasingly uncertain future.

Examining communities' coping and adaptation capacities reveals key aspects of farmers' sensitivity and resilience and can inform new strategies for reducing vulnerability. Scientists long took a vulnerability-as-exposure view focusing on physical vulnerability in strictly biophysical terms (White 1964; Burton et al. 1993). These studies addressed immediate causes rather than the socioeconomic, political, and structural drivers of vulnerability (Cutter et al. 2003). Vulnerability has also been discussed in terms of the limited capacity of individuals, groups, and communities to respond to stresses such as food security and other development issues (Chambers 1989; Watts and Bohle 1993; Blaikie et al. 1994). We see vulnerability as the confluence of multidimensional processes, including climate change, and explore people's responses within evolving economic and institutional contexts.

The concept of 'response' in this paper refers to the wide-ranging set of actions undertaken by local farmers in reaction to adverse impacts in different biophysical and political economic settings. Responses may not be adaptive or sustainable, or even part of a defined strategy. They can be spontaneous and may include shifts that fail to reduce risk and even increase vulnerability. Coping is defined as a short-term action designed to ward off immediate risk, rather than an adjustment to continuous or permanent threats. In fact, relying on coping strategies may increase vulnerability in the long term (Schipper 2009). Adaptation, done by different actors at different levels of consciousness, purpose, and timing, is a process of adjusting to changes in variables that influence human well-being and survival (including those other than climate-induced changes).

In order to better understand local adaptations to water stress, we undertook case studies to explore spatial and temporal vulnerability by examining coping mechanisms and adaptive strategies adopted by farmers in three mountain communities in Yunnan province. We also focused on two periods—the People's Commune (1960s–1970s) and the Household Responsibility System (1980s–2000s). The two periods capture different ecological

settings and major shifts in local socioeconomic and political conditions. The case studies document both coping strategies and adaptations to water stress, as well as emerging risks and constraints that could make responses unsustainable over time. We then examine the implications of implementing longer-term climate adaptation policies in mountainous Yunnan.

Methods

Fieldwork was conducted in the Longyang district of Baoshan Municipality in Yunnan province, Southwest China. This area lies in the upper watershed of the Salween River. Baoshan is one of the foremost agricultural production areas in Yunnan. As in other rural areas in China, Baoshans' community institutions have gone through two major historical phases: the People's Commune before 1978 and the Household Responsibility System (HRS) since 1979. During the People's Commune phase, all assets (land, machinery, and livestock) were collectivized, and land use was centrally planned. The government allocated grain production quotas to each commune. As labor was organized collectively for farming and infrastructure development, the government was able to mobilize massive numbers of people to construct reservoirs, irrigation channels, drainage systems, and terraces. Once completed, projects were either maintained by government technicians or by the communes. In the early 1980s after the dissolution of the communes, the HRS was gradually introduced. Farmland was allocated to individual households according to the size of families and availability of land. Individual households were allowed to make decisions about agricultural production and to sell their products on the market. While some facilities have been privatized today, large infrastructure is still in the hands of local government or collectively owned but managed through contracts with private parties. Rural people are still subject to government programs. For example, after catastrophic floods occurred in the Yangtze Basin in 1998, large-scale tree planting on sloping farmland was implemented with the goal of reducing soil erosion, landslides and flooding (Xu 2011).

There are three main agroecological zones in the study area: mountain uplands that primarily produce food crops; the valley area along the Salween River which produces a variety of subtropical cash crops; and plains surrounding the urban area of Longyang district/Baoshan City, which has good irrigation facilities and is a centre for tobacco production (Wilkes 2009).

The three case study villages, Daojie and Taokong at lower elevations and Baicai at a relatively higher elevation, were selected based on a set of criteria that included agroecological conditions, water stresses faced, availability of hydrometeorological data, existing institutional linkages, accessibility, and regional representativeness of major agroecosystems (Fig. 2). The villages are situated at elevations between 720 and 2,600 m and differ in socioeconomic and ecological characteristics and water-related vulnerabilities (Table 1).

To assess the existing knowledge, we performed a literature review and read local project reports and action plans on adaptation strategies to climate-induced hazards. This review provided a platform for the fieldwork carried out during the project.

Hydrometeorological trend analysis

In the general region, there are several meteorological stations with long-term records, but two of these lie some distance away from our study sites. We used Longyang station for long-term records and average elevation for our three sites. Kejie Hydrological Station, located downstream of Longyang District and with daily discharge data spanning over 40 years, provided hydrological data. Hydrological and meteorological data were also provided by the Baoshan Department of Hydrology and Meteorology.

Field assessment

Preparation included a regional fieldwork-planning workshop, small group meetings to finalize site selection, and rapid appraisal visits to identify the three study sites. Fieldwork was carried out between 2008 and 2010. Our first aim was to assess and document water utilization. We used field transect walks and participatory observation to collect data on how and to what extent water was used in households, agricultural production, and for energy and industrial purposes. We also documented the impacts of water stress on livelihoods through focused group discussion and semi-structured interviews with key informants including village leaders, elders, water users, and managers. Our third aim was to understand adaptation strategies in households and at the community level: who was doing what and when, and who was in charge of water security. We also examined whether collective action (both structured and non-structured) was taking place to cope and/or adapt to water stresses. Interviews were undertaken with key informants including farmers, senior villagers, village leaders, foresters, and government officials. In addition, ten to fifteen households in each village were randomly selected and interviewed. A questionnaire was delivered to 61 interviewees, designed to gather data on how households or groups (women, the poor, and young people) responded to water stresses. Participatory observation supplemented the data on the existing land, water, and forest practices and infrastructure.

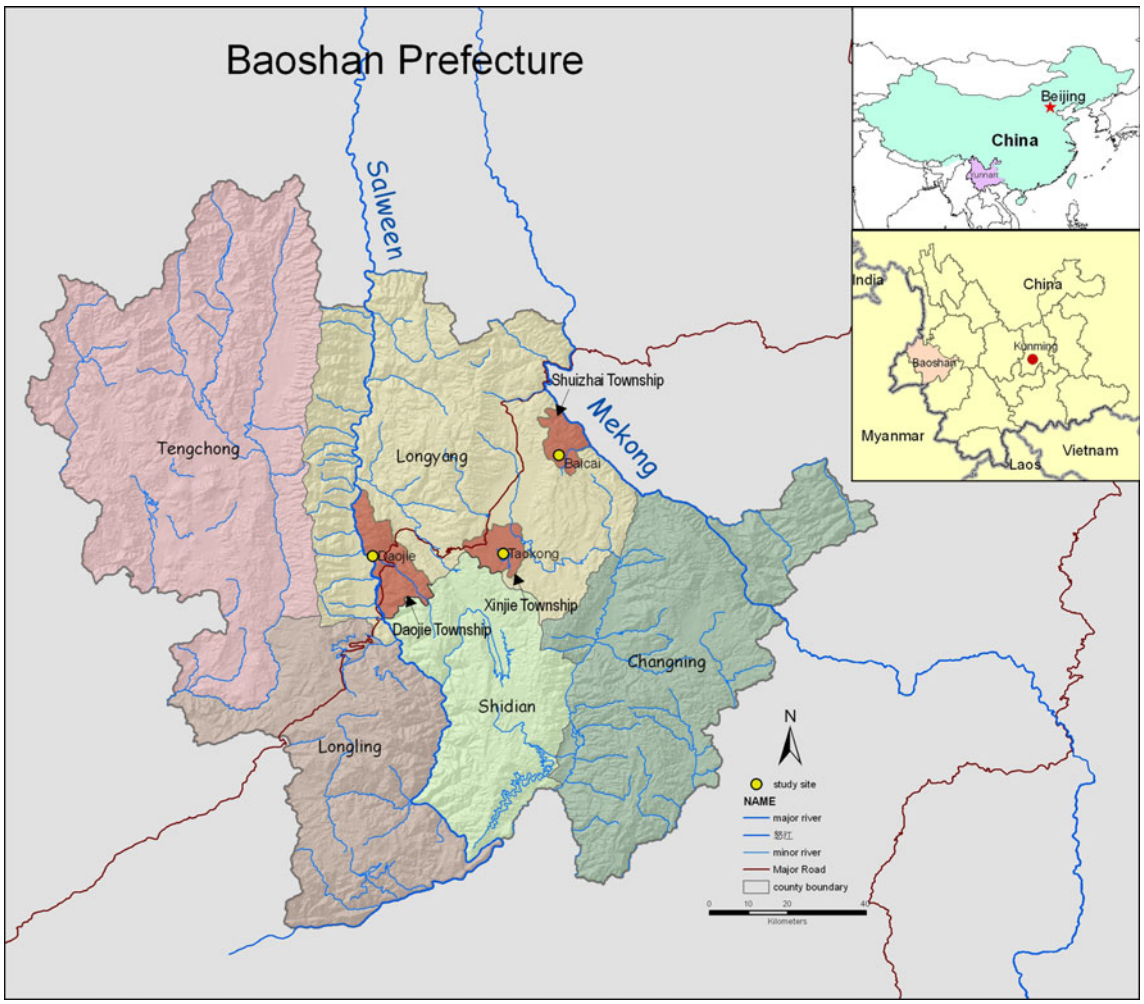

Fig. 2 Location of the three study sites. *Source* Centre for Mountain Ecosystem Studies, Kunming Institute of Botany 2009

Communication about concepts such as climate change, vulnerability, and adaptation was carried out in the villagers' own language, and less-recognized phrases such as 'climate change' were replaced by 'changes in rainfall' or 'differences in temperature'. Events related to water stresses and hazards about which villagers still retained vivid memories were discussed first.

Results

Climate change

Using regional data from Longyang District from 1965 to 2005 (Fig. 3a), annual average temperature has shown a general increasing trend. In Daojie villages' dry-hot valley location, to the contrary, there was a decreasing trend in average annual temperature from 1959 to 1996 (Fig. 3b).

For annual rainfall and runoff, there was no significant change trend detected at the regional level in the Longyang District of Baoshan. However, data from 1965–1986 to 1987–2005 indicate a gradual change in monsoon season precipitation; this implies less water availability during the main summer crop-growing period (Ma et al. 2009). Similar to the overall trend throughout Yunnan, Longyang District has become warmer in past half-century. Since 1960, the number of rainy days has decreased, and the number of extreme events (torrential rains, droughts) has increased (Zhou et al. 2011).

Local impacts of water stresses

Local impacts of changes in climate and water resources in the study sites varied greatly depending on biophysical factors (elevation, slope, vegetation, land cover) as well as socioeconomic vulnerability (access to infrastructure, technology, and markets).

Table 1 Characteristics of the three selected villages in Baoshan, Yunnan, China

	Low elevation Village A: Daojie	Intermediate elevation Village B: Taokong	High elevation Village C: Baicai
Elevation (m)	720–800	1,300–1,600	2,130–2,520
Age of the settlements (year)	About 50	200–300	100–200
Location	Downstream (Salween watershed)	Downstream (Salween watershed)	Upstream (Mekong watershed)
Transportation and market access	Along major paved road, 10-min drive from county town, bus connections to bigger towns	10-min walk from major paved road, bus connections to bigger towns	Dirt road, half-hour drive to nearest town
No. of households	1,052	1,458	382
Electricity	Yes	Yes	Yes
Irrigation channels	Yes	Yes	Yes
Climate	Hot, low precipitation, high evaporation	Medium-to-warm temperature, medium precipitation and evaporation	Low temperatures, high precipitation, and low evaporation
Temperature trend	Decreasing	Increasing	Increasing
Water sources	Streams (seasonal)	Stream, and close to major reservoirs (seasonal)	Springs (perennial)
Less rainfall with too little water supply for crops	Yes, April–July	Yes, April–June	No
Rain with too much water supply for crops	No	Yes, September–October	Yes, February, September–November
Major stress as perceived by the community	Water shortage in spring and droughts	Water shortage in spring and hail in summer/autumn and droughts	Too much water in spring and autumn and flood/landslide risks in the past.
Main Impacts	Impacting on agricultural and livestock production, income	Impacting on agricultural and livestock production, food security, and income	Impacting on agricultural production and destroying houses
Main cash income sources	Winter vegetables, animal husbandry, off-farm work	Tobacco, animal husbandry, off-farm work	Animal husbandry, forestry, off-farm work
Population trends	Increasing	Increasing	Decreasing

Source Su et al. (2009)

Daojie: differentiated impacts of water shortages

Situated along the Salween River, Daojie is located in one of Yunnan' dry-hot valleys where tropical and sub-tropical crops and off-season vegetables are grown. Since the 1970s, extreme climatic events in Daojie have destroyed farmlands, so water infrastructure (reservoirs and irrigation cannels) has been constructed for water security. Driven by market forces and government policies, new cropping patterns featuring off-season vegetables were introduced during the HRS period. These crops demand more water particularly during the dry season. With most arable land in Daojie rain-fed, farmers reported declining water supplies for both irrigated and rain-fed fields. They estimated a 30 % decline in spring water flows in irrigation channels since the 1980s. From January to April, decreasing rainfall combined with increasing competition and demand for water resources from upstream farming resulted in almost all Daojie farmers suffering from water shortages. Differentiated impacts are evident with households located upstream or closer to irrigation channels facing fewer impacts than those located downstream. Some villagers living downstream have had to irrigate at night during the dry season, since they were unable to get any water during the day. With their sleep schedules and daily routines affected, these farmers often cultivate less water-intensive crops or give up paddy rice altogether. In addition, households further removed from irrigation channels have to pay more for water. These farmers also experience increased workloads and are more affected by drought which, in turn, increases their reliance on irrigation services.

Taokong: competing demands for irrigation water

In Taokong, villagers do not get enough water due to a reduction in water storage capacity in the reservoir feeding their irrigation system. This is due to the sediment that has

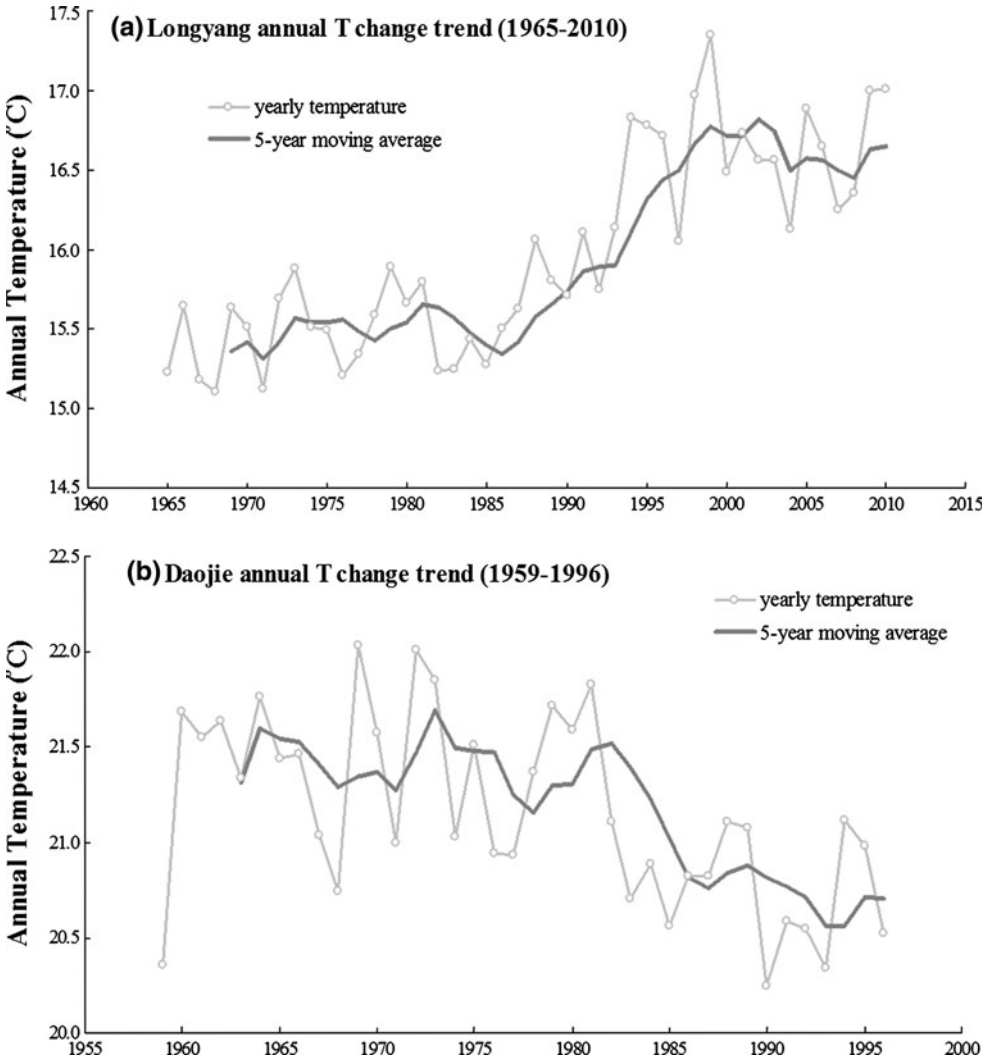

Fig. 3 The annual temperature change trend of Longyang and Daojie Stations. *Source* Ma et al. (2009)

been accumulating since the 1950s. Increasing precipitation intensity has also contributed to increasing sediment load. Since the HRS was introduced, collective management has also been weakened. And today, there is an increasing water demand due to market-driven agricultural intensification and urbanization in Baoshan City located about 50 km away. The largest reservoir that used to provide water mainly for irrigation is now also used for drinking water. The quality of drinking water is deteriorating because it is mixed with water used for irrigation and polluted by runoff containing agricultural chemicals.

In Taokong, irrigation is almost the only way to deal with the increasing risk of drought. Farmers reported that if there is not enough water during the planting season, sowing can be delayed by 15 days with the risk that a prolonged drought could mean losing the entire crop. Yet, with the HRS, farmers lack a collective action mechanism to repair the irrigation system. Since 2000, each household has paid fees to use reservoir water and pumping stations. As in Daojie, however, location matters-households further away from and higher above the pumping stations incur greater irrigation costs. This creates inequities since, in a good year, irrigation is required for 40–50 h in the spring and for 200 h in the autumn, while 1,000 total hours of irrigation may be needed in a difficult year.

Baicai: flash floods and natural risks

Located on steep upland slopes at a higher elevation, Baicai farmers used to face regular flash floods and landslides, especially after intense rainfalls. Unlike the two lower elevation study sites, drier and hotter years are not seen as harmful since Baicai has government-subsidized water storage. Control of landslides and livelihood diversification is the chief local concerns. To increase livelihood diversification, Baicai's 2004–2007 economic development plan made livestock a priority, and farmers began to replace traditional field-extensive grazing practices with a stall and fodder-based system. However, this transition is still incomplete, and there is an increasing conflict between

livestock and afforestation efforts to control landslides and erosion. Livestock raising also requires purchasing additional grain for feed since farmers now have less access to arable land on steep slopes due to government-supported tree planting through the 'Grain for Green' Program.

While Baicai seems to have adapted to water stress well compared with Daojie and Taokong, off-farm income is important for almost every household with more than 95 % allocating some labor to temporary or permanent off-farm work. Almost all farmers maintained that they would not permanently leave Baicai, but about 25 % of all households interviewed had some members who have already migrated to urban locations.

Adaptive responses to water stress and hazards

People in all three study sites have used both short- and long-term responses to cope with recurrent water stresses. In Baicai, the main responses have involved irrigation, crop selection, altered cropping patterns, and afforestation. As the below results show, Daojie and Taokong are more similar since they are at lower elevations, but in all three villages peoples' individual and collective responses to water stresses have been quite different during the Peoples Commune and Household Responsibility System periods.

Emerging individual responses

In all villages, centralized planning during the 'People's Commune' period prevented individuals from developing coping strategies to water stresses. On the other hand, although during the People's Commune workers were mobilized to develop water infrastructure, plans often failed to address local, site-specific water risks for households unless serious disasters affected the entire village. In addition, centralized agricultural production programs did little to invest in a range of livelihood alternatives. When water-induced climatic disaster occurred, local farmers suffered to a greater extent, for longer periods, and with slower recovery than at present.

This changed dramatically with the onset of the HRS. Individual farmers could now be more sensitive to climate-related stimuli such as too much or too little water. Due to decentralized land-use and farming decision making, they were able to develop self-adaptive capacity. Local people also gained improved access to various markets and some government services. Since 1983, at all three sites, the following major strategies have evolved to address water-related climatic risks.

Changing crop varieties and patterns When water supplies are low during the summer cropping season, some paddy fields are now planted with maize, yams, or beans although this has caused some reduction in income since prices are lower for these crops than for rice. In Taokong, 90 % of sampled households have changed their cropping patterns over the past 10–20 years; 26 % of the respondents attribute this to long-term water shortages, 20 % to recent drought, and 46 % to the higher economic value and better access to markets for new crops.

In Daojie, crop variety and cropping patterns have been changing as well. After the HRS was introduced, farmers shifted from double to single cropping for rice, which significantly reduced water use as well as water uncertainty in the spring. During the past 5 years, 100 % of sampled households had changed their cropping patterns with 75 % of respondents attributing this to lack of water. When asked what measures they take to cope with serious drought, 54 % of sampled households said they changed crops from paddy to maize, and 87.5 % postponed cultivation by about 15–30 days. Only 4 % selected and used drought-resistant varieties. Households whose paddy fields are far from the main irrigation channels now choose to grow a later-season variety since they have to wait for the households closer to the source to finish using water before they can gain access. Farmers have also diversified into growing sweet potatoes, tobacco, or vegetables in the autumn. In both villages, many paddy fields have been converted into vegetable fields for winter cropping; when water shortages persist, maize becomes the short-term substitute for rice. Both maize and vegetables require less water than rice, although another reason for this shift to vegetables is their high economic return.

Even after villagers took these measures, some effects of drought during recent years were not offset, and householders expected that it would take some time to recover to 'normal' conditions. In Taokong, the poorest households often gave up agricultural production during severe drought years with 11 % expecting to need at least 1–3 years to recover and 29 % expecting to need 1 year. The wealthiest 33 % of households expected to need only a few months; 27 % did not know how long it would take to recover because impacts were still being experienced. In Daojie, these household data were 8, 21, 50, and 21 %, respectively.

Use of water-saving technologies In Daojie, dry rice has been widely adopted in paddy agriculture. Potted seedlings are now commonly used for maize and tobacco in order to deal with early spring drought and low temperature. In Baicai, plastic sheeting is being used on most upland maize and vegetables to retain moisture and maintain warm temperatures.

Improved irrigation In Daojie, some fields have a high clay content that can retain water longer. Villagers thus

make small water tanks that can store extra water during the winter irrigation season as well as channels along their fields to direct water to crop roots. Some better-off households whose fields are near the Salween River have purchased water pumps to draw water from the mainstream. Poorer households sometimes rent these pump when there is a severe water shortage.

Household livelihood strategies In all three villages, poor households are more vulnerable to climate-related impacts on their livelihoods as they often lack alternative income sources. During serious droughts, poorer villagers borrow grain or cash and raise fewer animals because they have less maize to feed livestock.

Off-farm work As drought occurrence has increased, the number of villagers leaving on seasonal migrations for off-farm work has risen. For example, in Taokong, most families have at least one member involved in off-farm work. During droughts, two or more family members often leave for off-farm work for long periods. As noted above, off-farm work is used extensively in Baicai.

Collective action in transition

Social organization and cooperation When water shortages occur, individual households' coping strategies often prove to be insufficient, competitive, or at odds with the needs of other households. This necessitates greater cooperation to adjust to climate variability and long-term water management needs. For example, in Taokong, water-stressed households built 'temporary dams' to divert water to irrigate their paddies, resulting in soil erosion and social conflicts with neighbors over water use. Eventually, cement dams were built through local consensus and collective decisions using government subsidies for construction materials.

Village-level rules Local institutions had been significantly weakened during/after the period in which the People's Commune dissolved. In recent years with increasing extreme climate events, village-level water management rules have been re-established. All three villages have implemented increased irrigation system maintenance. In Daojie, when there is not enough water for irrigation, the village committee (VC) implements a system of distribution and rotation among village groups. Villagers from each group also watch over the main irrigation channels to ensure that distribution is fair. When water supplies are low, water fees become three times higher; this increases costs, but results from a collective villager decision.

Water storage In Daojie, water was originally provided for free but, in 2003, the VC set up drinking water regulations in order to improve the overall efficiency of water use. Since 2006, a water quota of 2 tons/person/month has also been established. If a household goes beyond the quota, the VC imposes a fine that is six times higher than the water fee. In response, most households have built small water tanks for dry season storage. This practice also benefits women as they are responsible for household chores, and the tanks reduce their workload.

Hiring contract managers In villages experiencing water shortages, hiring water irrigation managers has become a common practice. In Taokong, village leaders hire contractors who are in charge of water pumping and guarding pump stations. In Daojie, contractors are selected through an open bidding process to manage the distribution of water for irrigation and drinking, but the maintenance of the irrigation system is still overseen by the VC or village groups. Baicai has not had to hire managers due to its relatively less water-stressed upland location.

Local adaptation: strategies and constraints

The three villages illustrate diverse responses to climate variability in the context of wider socioeconomic transformation in Southwest China. Impacts are experienced differently depending on geographical, social, and economic factors. The impacts of water stresses range from flash floods and landslides in Baicai to shortages resulting from competing demands for irrigation water in Daojie and Taokong. So the responses of villagers also vary; in upland Baicai, afforestation was adopted to reduce land degradation and landslides, while at middle and lower elevations in Daojie and Taokong, changing cropping patterns and improved storage systems were employed.

Villagers also responded to stresses differently across the time periods we assessed. During the Peoples Commune period, local institutions used centralized collective action to ensure that all villagers had equal access to water resources. Though these resources might not have been used efficiently, the large-scale water infrastructure constructed during this period still provides the physical basis for people's adaptations to extreme climate events. In both Daojie and Taokong, one reason why villagers have been able to cope relatively well with drought is because of this historical investment in irrigation infrastructure. Yet, although the Peoples Commune policies allowed villagers to make adaptive responses at the village level, individual households' abilities to respond to climate risks and impacts were constrained.

Land-use decision making has also influenced local responses to water stress. During the Commune Period, people had very little discretionary authority to make decisions about land use, and this limited their ability to adapt to changing conditions. For example, in Daojie in the late 1950s, people were forced to move to a dry-and-hot valley to explore production opportunities there without any consideration of climate conditions. Since the transition to the HRS, people have had more flexibility to make their own choices, and farmers in all three villages have had more incentives to innovate. This has led in part to the changed cropping patterns, agricultural intensification, new irrigation methods, and diversified livelihoods described here.

Local leadership has also been unleashed by the HRS. In Baicai, village leaders introduced afforestation activities to cope with landslides and soil and water erosion. These strategies evolved into long-term adaptations for general disaster management, and the village is now relatively well-prepared for future water stresses. In Taokong, in response to increasing demands for water, local government has established rules for water distribution and management. However, these rules only help with the equitable distribution of irrigation water to a certain extent because the township government is not directly involved in enforcement.

The above examples illustrate that the HRS has led to innovation, but dysfunctions that constrain farmer adaptations have also occurred. Due to the lack of government enforcement, poor maintenance of both old and new infrastructure is currently causing water shortages. For example, in Taokong one main irrigation channel from the Daba reservoir built in 1956 is now in disrepair and shows signs of collapse. With the transition to the HRS, this water infrastructure received little maintenance, and today, much of it does not function properly and/or fails to reach individual farmers fields. As illustrated by the 2010 drought, there has not enough investment in small-scale infrastructure—ponds, small reservoirs, and canals—to distribute water to households in the hardest-hit areas.

Government agenda also have led to problems. Because of the local government dependence on tax revenues from cash crops (especially tobacco and sugarcane), extension services are biased toward the production of these crops. For example, tobacco farmers receive subsidies for nurseries and transplanting that farmers growing other crops in the study area do not receive. In Baoshan, the HRS has engendered a conflict between maintaining/improving water infrastructure and providing adequate institutional development to support better water management. Currently, the government is promoting the establishment of water user associations in areas that have received new infrastructure, but support for improving water management is not being provided to areas with *existing* water infrastructure. Flood and Drought Management Coordination Committees exist but provide only limited support to rural areas such as our study sites.

Water shortages may have triggered adaptation across the three study sites, but economic drivers including access to markets, commodity prices, increased productivity driven by technical agricultural improvements (e.g., increased use of fertilizers), and relative wealth also play key roles. Markets impact farmers in complex ways. For instance, in Daojie, even though farmers are facing serious water shortages, many have chosen to grow high-value, high water-demand crops. Price influences farmer behavior, and few households have planted relatively low-value, drought-resistant varieties. In both Daojie and Taokong, once a drought occurs, the extent to which households are able to cope depends on how much they are engaged in diversified agricultural practices that enable them to switch to other crops. Off-farm income generation is another form of economic diversification. Such employment is one of the main sources of income for many villagers, especially in Baicai where 95 % of the sampled households have at least one person engaged in this work. All three villages have easy access to fertilizers and pesticides which allow farmers to select cash crop varieties that require more water along with sizeable chemical inputs. This can lead to negative impacts on water quality and human health, but poorly educated villagers remain unaware of these impacts. And in general, across all three villages, poor households are more vulnerable to water stress. Poor people often lack preparedness for water-induced disasters, access to emergency relief afterward, and alternative income sources to assist with recovery. Overall, at all three study sites, most farmers' main concern is the economic benefit derived from their production activities.

Discussion and conclusion

Rural farmers in Yunnan have faced a range of impacts from changes in climate to dramatic socioeconomic transformations with concomitant shifts in government policies. However, this study confirms that with respect to vulnerabilities associated with water-related stresses, local communities possess the innovative knowledge and practices to respond. Yet, farmers also continue to follow short-term economic signals. As the three-decade-long process of economic reform in China continues to bring substantial numbers of rural people out of poverty, urbanization is creating more opportunities for farmers to grow niche products and engage in off-farm employment that contributes to diversified livelihoods. However, these socioeconomic changes combine with uncertainty in climatic

trends to compound pressures on mountain communities. In our study areas, high-input agriculture has become commonplace, including the production of off-season vegetables in dry-hot valleys, cash crop tobacco at middle elevations, and high-yield varieties of corn in the uplands. Typically grown as monocultures, these crops only produce high yields in years with optimal weather or through the use of greenhouse nurseries combined with outdoor plastic film protection later in the growing season. Furthermore, these practices depend on large quantities of chemical fertilizers leading to poorly studied and likely negative effects on land and human health, increasing crop vulnerability to pests, and contributions to greenhouse gas emissions (IFA 2009; Kahrl et al. 2010).

Overall, farmers' responses to changes in availability of water in Yunnan must be understood through the legacy of the Peoples Commune-era establishment of water infrastructure, HRS shifts in property regimes along with weakening of water infrastructure and community institutions and constraints imposed by recent government policies. As a result, adaptation by farmers in rural Yunnan has been oriented toward short-term market rewards through crop substitution and income diversification. Long-term adaptation planning involving local stakeholders has been neglected.

Potential adaptation options

The three villages in our study each possess unique vulnerability profiles, have different capacities for responding and adapting to climate impacts, and, therefore, have followed different patterns of adaptive response. So far, Baicai has managed water stresses well whereas Daojie and Taokong have responded adequately in the short-term though the future is uncertain. In general, from this study, we have learned that improving irrigation investment and management while diversifying both on-farm and off-farm production are worthwhile for short-term coping with water stresses. However, households with different asset bases have varying capacities for using these options. And over the past 20 years, as farmers have switched from complete dependency on agriculture to diversified market crops and livelihoods, there are risks that these responses may become unsustainable. Given the volatility of urban and global markets for agricultural products and the inherent instability of off-farm work, current strategies must be reinforced by long-term ecological and socioeconomic adaptations.

Such potential adaptation options at the community level could be focused on technological developments; water infrastructure and management; farm production practices; stakeholder participation; and government programs. For technological development, local and central governments could provide more support for farmers by developing new drought-tolerant crop varieties and planning for more water-efficient conservation agriculture practices. There are many low-cost practices that have yet to be applied widely in rural Yunnan including micro-drip irrigation, water recycling, and precision fertilizer application (Wu 2010). Local government extension services could also offer early warning weather forecasting that may lead to cropping pattern adjustments.

Investment in small-scale water infrastructure is one of the best options for addressing problems of water accessibility in Yunnans' mountain regions. Water storage is one way to cope with droughts, particularly during planting season in the early monsoon. Rehabilitating aging infrastructure would dramatically increase water storage efficiency. New construction of small-scale reservoirs in mid-elevation valleys should be explored. Improving small-scale infrastructure such as banking rivers, increasing drainage, building retaining walls, and terracing fields can be done.

Farm production practices will continue to be influenced by markets and policies beyond rural Yunnan. The trick is to help farmers adjust ahead of market changes. For example, recent food safety standards imposed by the central government may lead to more green farming/organic cropping opportunities that farmers may benefit from if such policy changes are communicated clearly to them. China is also facing high-risk climate impacts and instituting payments for environmental services to farmers for growing crops that reduce those risks can broaden food production goals to include ecological benefits (Information Office/State Council 2011).

China is a growing economic power and has developed top–down 'national adaptation plans' for climate change. This approach can only be implemented effectively, however, with the active participation of local people in planning, monitoring, and evaluation. Community institutions and local leadership are necessary enablers of the capacity of household-level stakeholders and village groups to deploy specific climate and water stress adaptation practices. In rural Yunnan, there is an urgent need to revive and/or create community-based organizations, such as water resource associations and vegetable cooperatives with legal, financial, and technical support from government agricultural, forestry, and irrigation line agencies. However, there are missing links between local government and local people. One way to establish such links would be to support multistakeholder discussions with farmers, local extension agents, and government officials to pool 'best-available' knowledge as a basis for adaptation. This remains a challenge in Chinas' top-down-oriented system.

Government assistance is needed to address the gaps between climate impacts, water stress drivers, and

community capacity; these cannot be managed solely by villagers. Yunnan receives significant amounts of state funding for afforestation and ecosystem restoration, but large-scale government efforts, such as tree planting under the 'Grain for Green Program', are not well-integrated into local watershed plans and disaster-risk management, and therefore can have negative environmental consequences (Xu 2011). It is difficult to see how China at the country scale and farmers at the local scale can adequately respond to the ongoing challenges of climate adaptation until these two are better integrated. It may be that new extreme climate events or water crises may trigger more integrative policies and practices, despite the fact that knowledge to move ahead already exists. Yet, the responsibility of central and local government lies not only in responding to emergencies (such as natural disasters related to climate change) but also with reducing long-term community vulnerability to climatic events (Wilhite 1995).

Research gaps and knowledge needs

A number of research gaps need to be addressed in order to better plan for climate adaptation in rural Yunnan. To begin, more data about local and regional climate trends should be collected. We have highlighted several adaptation strategies currently employed in the three study villages, but we remain unclear about how many other villages in the region have adopted similar strategies. And, we report only what farmers are doing and their perceptions of how effective their strategies may be. Follow-up studies to document adaptation effectiveness over time are needed. Comparative work that explores barriers to local adaptation and how these can be reduced should be done. At the same time, information about successful adaptation strategies must be disseminated to other locations for potential adoption; though local context always matters in climate adaptation, every village does not have to recreate the wheel (Brunner and Lynch 2010).

Linking adaptation to government policy

As can be seen from our list of adaptation options, state policies will continue to play a key role in shaping the extent to which rural households and villages have the capacity to adapt to the risks induced by climate change. For example, agricultural extension and irrigation infrastructure investments remain strongly affected by provincial fiscal policy that privileges cash crop production (Wilkes 2009). In China, however, climate change and climate change adaption are emerging as new policy domains that are being superimposed onto the existing sectoral and regional development policies. Since most local-level policies are a response to directives from higher levels of government, there is a great opportunity to integrate climate science and adaptation into sectoral policies and for these to inform plans for local-level action. Both science-based planning and the political renewal of Chinas' top-down system call for synergy among local and central governments in order to develop integrated climate policy that leads to both successful farmer adaptations and a stronger China over the long term.

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