Climatic Change (2013) 120:727–739
DOI 10.1007/s10584-013-0842-0

Climate change and adaptation: an integrated framework linking social and physical aspects in poorly-gauged regions

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Received: 4 December 2012 / Accepted: 11 July 2013 / Published online: 1 August 2013

Abstract Various frameworks related to climate change and adaptations that have been developed to date have notable benefits as well as significant limitations. It is not always practical to implement advanced climate change frameworks in situations with limited data availability. Social aspects, such as people's experience and perception, are often under-prioritized. Therefore, this study introduces an integrated framework linking social and physical aspects of climate change to assess its impacts on water resources and to evaluate differing adaptation options in poorly gauged basins. A case study of the Kali Gandaki River Basin (KGRB) in western Nepal is presented to demonstrate the applicability of this framework. Results of the study show that people of the mountainous Mustang district in the KGRB have perceived climate change or climate variability, its impacts on water resources, as well as other water-related issues and potential adaptations or responses. Furthermore, evaluation of people's perception using available physical data confirms the increase in temperature and average annual discharge in the Kali Gandaki River as well as poor water use, as a major problem at all levels in the basin. Despite increasing water availability, a concurrent increase in water use is difficult due to topographic constraints on irrigation development. However, the impacts of climate change are particularly severe in

Electronic supplementary material The online version of this article (doi:10.1007/s10584-013-0842-0) contains supplementary material, which is available to authorized users.

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Mustang, owing to the fact that a large proportion of the population depends on a climate-sensitive livelihood like agriculture. Therefore, various adaptation options are identified in the agricultural sector, and one relevant option is further evaluated. The framework developed in this study has the potential to be further applied to other poorly gauged basins.

1 Introduction

Climate change is considered the most critical global challenge of this century. An overwhelming body of scientific evidence now clearly indicates that climate change is a serious and urgent issue (Stern 2007). By extension, increasing impacts of climate change on water resources is becoming one of the major concerns across the globe. As the evidence for rapid climate change has already been observed on global, regional, and local scales over the last few decades, research-based knowledge is crucial to effectively deal with sector-specific impacts of climate change by means of enabling the process of adaptation (Hofmann et al. 2011). In response to the need to enhance scientific understanding of climate change, its impacts on diverse sectors, and human responses, much research has already begun and expanded across both the social and physical sciences, providing qualitative and quantitative information, respectively.

Carter et al. (1994) presented a seven-step analytical framework for assessing climate change and its impacts, and to plan adaptation strategies; this was later characterized as a “top-down” approach by Dessai and Hulme (2004). They subsequently introduced an alternative “top-down and bottom-up” approach to inform climate change adaptation policy. However, this study did not provide much discussion on the application of this approach. Byg and Salick (2009) shifted the focus to local perceptions, beliefs, and indigenous or traditional knowledge of climate change. Hallegatte (2009) particularly focused on adaptation to climate change, while Conway and Schipper (2011) analyzed climatic trends and variability to assist in understanding protracted climatic changes. Cai et al. (2011) focused on an integrated modeling approach for climate change impact analysis and adaptation planning. Furthermore, Jones and Preston (2011) presented a risk management framework to integrate adaptation approaches with complementary mitigation techniques. However, knowledge on climate change is fragmentary, based on disparate case studies, focusing on distinct aspects with inconsistent terminologies. A recent study by Kalaugher et al. (2012) went one step further to illustrate the complementarities between the bottom-up and top-down approaches to analyze climate change adaptation strategies. However, this study was limited to small farm scale analysis. Despite the remarkable progress in climate change impact assessment and adaptation studies, most usually concentrate on quantitative science and physical modeling and consider higher order socio-economic impacts only if quantitative models are available to integrate to the biophysical effects. Social aspects, such as people’s observation and perception of climate change, form long-term datasets developed over years of trial and experience (Byg and Salick 2009), are often less prioritized. Additionally, it is not always practical to implement advanced modeling frameworks requiring a wide range of data in data-poor situations (i.e., in poorly gauged regions). Therefore, it is important to develop a framework that can assess the effects of climate change impacts on water resources and can evaluate adaptation options using available social and physical data in poorly gauged regions.

In earlier days, when systematic climate data recording systems were absent, social aspects, people’s observations, and perception were the only basis for understanding the ongoing processes and for taking action. With the advent of new technologies, climate change studies are based on advanced frameworks involving data from various sources (hydro-meteorological stations, satellite sources, etc.). However, it is not possible to define climate change or develop sustainable responses without understanding social or individual perceptions of climate change (Dessai et al. 2004). Furthermore, social and physical aspects, together, can provide a practical basis for understanding the extent to which people have perceived climate change and its impacts on water resources and adapted to related problems in data-poor regions. Comparison of people's perception with physical datasets or their derivatives (resulting from various approaches, such as hydro-climatic trends analysis, hydrological modeling, and water poverty analysis) helps evaluate whether the perception aligns with changing climate. For example, if people have perceived warming in the past 15 years, and the examination of temperature records, through calculation of temperature indices and their trends analysis, shows an increasing trend, then people's perception is complemented with physical measurement. People's perception can be used as a basis to understand and respond to climate change and variability, and can be extrapolated in areas that are otherwise, data-poor. Therefore, the overall objective of this paper is to develop an integrated framework linking social and physical aspects, and demonstrate its application in one case study basin in western Nepal. The framework is intended to be applicable to all poorly gauged regions and is expected to bring together the broader issues of climate change and water resource management under a single umbrella.

2 Methods and materials

2.1 Description of methodology framework

This section presents an integrated framework for assessing the impacts of climate change on water resources and evaluating adaptation options in a poorly gauged region (see Fig. 1). The framework is based on the assumption that the linkage of social and physical aspects will help provide the best and most realistic evaluation of climate problems in situations with limited data availability. It includes three main steps: (1) documentation and analysis of people's perception of climate change or variability, its impacts, water-related issues, and adaptation; (2) evaluation of people's perception; and (3) responses to climate change (e.g., adaptation options).

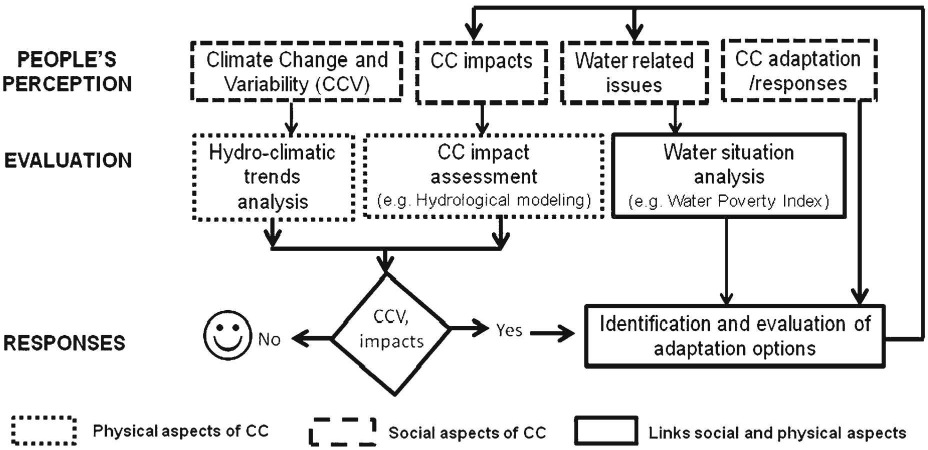

Fig. 1 An integrated framework proposed in this study

2.1.1 People's perception

People's perception can reflect local issues or concerns (Danielsen et al. 2005) and reveals the actual impacts of climate change on people's lives, mainly related to local factors and may not be easily estimated through models. Knowledge of the perception of people directly affected by climate change is important and essential in planning adaptation measures (Deressa et al. 2009) because people's perception greatly influences decisions on their response to climate change (Byg and Salick 2009). For those changes that are perceived, most people take remedial action to counteract the impacts of climate change (Balete 2011). Perception of adaptation reveals those ongoing actions and responses, as well as barriers and future opportunities, which will guide adaptation planning. It is therefore important to document and understand people's perception in relation to their observations and interpretations of climate change and variability, in addition to its impacts, water-related issues, and responses, including adaptation; this is included as the first step in the framework.

People's perception is primarily documented through qualitative rapid rural appraisal tools, such as direct field observations, transect walks, focal group discussions, key informant interviews, and time line establishments, among others. In addition to these qualitative tools, household surveys are conducted using structured questionnaires. Simple descriptive statistics and chi-square (χ^2) tests are performed to investigate the relationship between people's perception and various climatic parameters. Additionally, qualitative information in the form of narrative experiences are also provided, bearing witness to the changing climate and increasing climatic variability in the study area. Secondary sources such as reports, papers, and books are also reviewed. A detailed methodology is described in Manandhar et al. (2011).

2.1.2 Evaluation

Confidence in interpretation of people's perception of climate change can be gained through its comparison with available physical datasets or their derivatives. Furthermore, balancing people's perception with scientific evidence for climate change provides important insights into climate change impacts, water-related issues and the way people respond to it, while simultaneously guiding future climate change adaptation processes (Kuruppu and Liverman 2011). Therefore, the second step of this framework involves evaluation of people's perception by comparing with available physical data and their derivatives. Three approaches are used during this step.

Firstly, the people's perception of climate change and variability, including changing temperature and rain, is evaluated by comparison with results from hydro-climatic trends analysis. Hydro-climatic trends analysis includes examination of annual and seasonal hydrological patterns, as well as various precipitation and temperature indices. The temperature and precipitation indices are calculated on an annual basis using RClimDex (1.0) (Zhang and Yang 2004). Many details of the methodology and indices are available in Manandhar et al. (2012b). Although extreme climatic events cannot be predicted with certainty, a proper assessment of existing hydro-climatic trends and people's perception of them can provide important knowledge for planning appropriate adaptation measures to address possible adverse effects.

Secondly, perception of the impacts of climate change on water resources (water availability) is evaluated by comparing it with the outcomes of hydrological models. Hydrological models can simulate runoff patterns under changing climatic conditions, which can help to demonstrate how far people's perception of changes in water resource availability is aligned with the model outcomes. Depending on data availability, a physically based distributed hydrological model developed at the University of Yamanashi based on block-wise use of TOPMODEL and the Muskingum–Cunge method (YHyM/BTOPMC), integrated with a simple degree–day-based snow accumulation/melt sub-model, is used to simulate runoff patterns under different perturbation scenarios. Further details of the methodology are available in Manandhar et al. (2012a).

Finally, perception of water-related issues is evaluated by comparing it with the results of water situation analysis. Various water situation analysis tools, including vulnerability index, adaptive capacity index, water poverty index (WPI), and others, have been used in previous studies (Pandey et al. 2009; Pandey et al. 2012). Among them, the WPI tool, which has been widely used to analyze water situations in different parts of the world, is used in this study. It considers physical, social, and economic aspects of water resources, and helps prioritize and focus adaptation planning in areas that have need for water. Detailed methodology of all steps is described in Manandhar et al. (2012c). Only current WPI is calculated using equal weight to WPI components and variables.

2.1.3 Responses

The issues of perception, interpretation, and decision-making are central to determining whether adaptation takes place and how it is carried out (Berkhout et al. 2006). Based on the results of people's perception and their evaluation, the framework advances to the final step: responses. If the climate change and variability and its impacts are confirmed, 187 then adaptation options are identified and evaluated, else is not proceeded. Evaluation of water-related issues using WPI results highlights the most needful areas in the water sector. People's perception of climate change adaptation gives an idea about ongoing adaptations and the local concerns or needs. Based on this information, location- and situation-specific adaptation options are reviewed in the most needful areas in the water sector. To be plausible, adaptation options must be: (1) appropriate from an environmental perspective; (2) cost-effective from an economical perspective; and (3) acceptable from social and cultural perspectives (Lioubimtseva and Henebry 2009). Therefore, among multiple adaptation options, the most relevant one is selected, evaluated, and recommended, which helps reduce the impacts of climate change on water resources and to solve water-related issues. Only one specified adaptation option is evaluated in this study, and detailed methodology is described in the Appendix-1. Evaluation of other plausible adaption options will further support adaptation planning.

2.2 Study area

There is little research-based knowledge on climate change in the poorly gauged Kali Gandaki River Basin (KGRB) (shown in Fig. 2). Earlier studies have shown that local people have already perceived climate change or variability (Nepal Trust for Nature Conservation and United Nations Environment Programme 2008; Manandhar et al. 2011) and response to the changes is urgent. Therefore, the KGRB is selected as a study area. It is characterized by inter- and intra-annual variations in precipitation and runoff. Despite seasonal variability and climatic change, most of the human population in the basin relies on water resources for subsistence. Land cover is broadly classified into four different categories: barren (23.4 %), cultivated (23.6 %), vegetation (51.3 %), and water bodies and glaciers (1.7 %). The basin is home to nearly 1.71 million people, most of which are concentrated in the central hills and are dependent on agriculture-based livelihoods. Mustang, the mountainous area of the KGRB, is selected as the case study district (a district is the third order administrative division in Nepal) to study people's perception and possible adaptation options to climate change. The district experiences diverse climate, ranging from tundra, arid type to alpine, cold temperate in higher and lower elevations, respectively. It is home to nearly 15 thousand people, scattered throughout the district, and nearly 65 % of them are involved in agriculture.

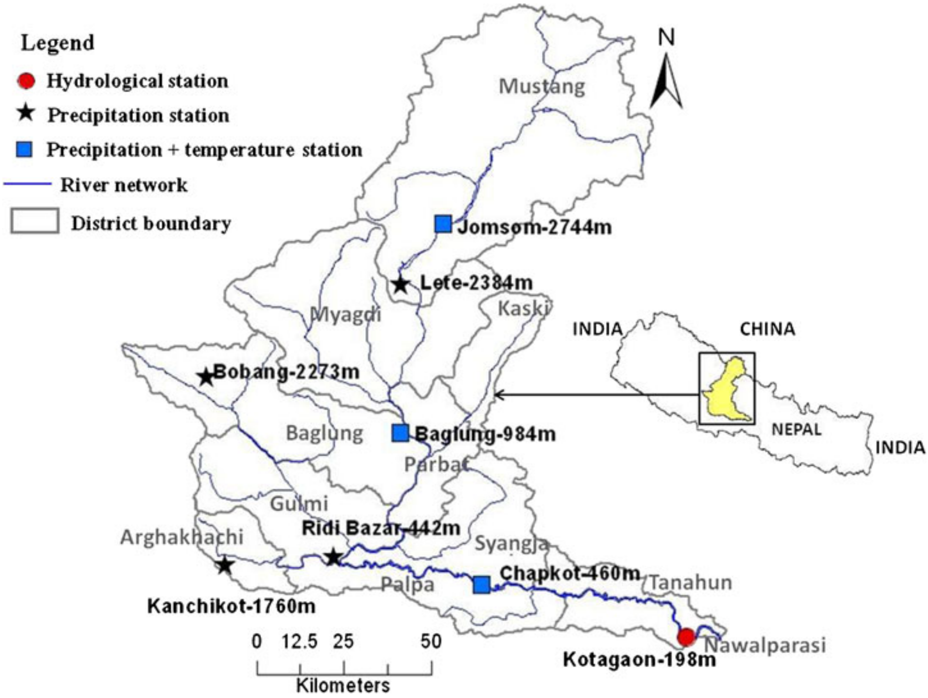

Fig. 2 Kali Gandaki River Basin in Western Nepal (Data source: river network from ICIMOD (2012), district boundary from NLUP (2012); location of precipitation and temperature stations from DHM (2010))

2.3 Data and sources

Data are collected from various sources as detailed in Table 1

3 Application of the framework to the KGRB, Nepal

3.1 People's perception of climate change and variabilities, impacts, water-related issues, and adaptations

People's perception of climate change and variabilities, impacts, water-related issues, and adaptation is examined in the Mustang district. Altogether, 155 households were surveyed using structured questionnaires. People of lower Mustang have been experiencing an increase in the amount and intensity of rainfall, which they describe as short but intense downpours in recent years, leading to leakage of muddy rooftops. However, erratic rainfall is observed throughout the district within and between seasons. Ninety two percent of locals in Mustang agree that there has been a decrease in the volume of snowfall and snow cover in the nearby mountains. More than 85 % of households interviewed perceived major changes in both summer and winter temperatures.

Increasing temperature has undoubtedly brought about some changes in the ecosystem, such as increasing evidence of mosquitoes, which were not found in the past, and a shift in the tree line. The increasing temperature has also gradually created more favorable conditions for the diversification of agriculture, but on the other hand, has also led to an increase in pests. Increasing temperatures have also led to melting of snow; locals have observed less snow in the mountains and a higher water

Table 1 Sources and details of data used in this study

Data	Source(s)
Administrative boundary	NLUP (2012)
Area, production, and import of apples in Nepal	FDD (2011)
Chemical fertilizers use rate	CBS (2004), Field survey (2010)
Digital Elevation Map (DEM), aspect, slope	Jarvis et al. (2008)
Domestic water use, people's perception related data, economic and social indicators for the assessment of apple cultivation, soil toxicity (pH)	Field survey (2011)
Drainage network	ICIMOD (2012)
Forest cover and wetland area	CBS (2008), CBS-Baglung (2009)
Irrigation coverage and cultivated area	DOI (2009), DADO-Mustang (2009)
Land cover	USGS (2011), NLUP (2012)
Literacy rate and GDP, Economically active population	CBS-Baglung (2009), CBS (2009)
Mean daily temperature (°C), diurnal temperature range (°C), vapor pressure (kPa), cloud cover (tenth), wind speed (m/s), extraterrestrial radiation (MJ day^{-2} m^{-2}), Daylight duration (hour)	CRU 2.0 datasets from IPCC (2011)
Non-agricultural employment	ICIMOD and CBS (2003), Field survey (2010)
Normalized Difference Vegetation Index (NDVI)	Tucker et al. (2005)
Observed discharge (m^3/s), Precipitation daily data (mm), temperature (°C)	DHM (2010)
Precipitation contour map	ICIMOD (2012)
Safe water and sanitation coverage	DWSS (2008, 2010)
Soil distribution map	FAO (2009)
Soil texture, depth, and drainage map	NLUP (2012), FAO (1995)

level in the Kali Gandaki River in recent years. More than 90 % of households have perceived water-related issues, either in the form of high rainfall variability, poor sanitation facilities, low vegetation coverage, limited water use, or high dependency on an agriculture-based livelihood. In addition to the descriptive statistics, the χ^2 tests suggest that climate change and variabilities perceived by local people are statistically significant at the 5 % level of significance, thus confirming that locals have perceived climate change or variability.

Alongside these quantitative results, some narrative experiences and observations of local people were also documented. Hom Bahadur Serchan, a 68-year-old resident of the Kunjo village in Mustang, still has a hazy memory of the winter of 1953. When he was a 12-year-old boy, snow cover in Kunjo was one-story high. Due to heavy snowfall, people were confined to the house, eating stored food, drinking melted ice water, and using it for cooking purposes, for sometimes up to an entire week. He said that, in the past, snow used to be thick on the mountains until the month of May, but that nowadays, it melts earlier, exposing the black surface and giving a dirty appearance to the mountain slopes. He appeared to be very concerned about the changes that are taking place. Another resident, Tek Bahadur Gurung, a 44-year-old resident from Jharkot village in Mustang, remembers that villagers did not grow vegetables and corn in Jharkot in the past, instead carrying them from the lower regions (Lete, Kunjo, and Kobang); but now the climate is changing, the area is favorable for cultivating different kinds of vegetables and corn.

Almost all households in Mustang are adapting to climate change and climate variability in one way or another. Climate change and variability, which manifests itself mainly through increasing rainfall and temperature, seems to be beneficial to farmers in the rain shadow and in the cold upland areas of Mustang. Changing climatic conditions in combination with an expansion of their market have also induced farmers to shift vegetable and apple growing to higher altitudes and to further promote crop diversification. In addition to this, farmers have also adopted changes in their cropping calendar, and branched out into tourism and other non-agricultural business.

3.2 Observed hydro-climatic trends

This section discusses hydro-climatic trends, the physical aspect of climate change, in the poorly gauged KGRB using available long-term datasets from 7 rain-, 3 temperature- and 1 discharge-gauging stations (see Fig. 2). Results assist in evaluating whether people have perceived climate change and variability correctly and further aid in understanding the hydro-climatic situation in the basin.

Temperature and precipitation trends The trends in temperature indices vary spatially within the study basin. At higher altitude (i.e., at the Jomsom station), temperature indices have statistically significant upward trends. Monthly maximum and minimum values of daily minimum temperatures increase, which supports the people's perception of increasing summer and winter temperatures. In addition, the number of cold nights is significantly decreasing and warm nights are becoming more frequent; indicating a prominent temperature rise in the mountainous region of the KGRB.

Unlike temperature indices, most precipitation indices exhibit roughly equal proportions of increasing and decreasing trends at all studied stations in the KGRB (refer Fig. 2 for location of stations). Moreover, only a small fraction of the station trends are statistically significant for any index. This shows that changes in precipitation are prominent in some areas but small and erratic, without any definite trend, at others. Looking for trends of consecutive dry days, an increase is seen at all the stations, with significant rise at Bobang. A significant increasing trend in consecutive wet days is found at Lete, while a mixed response is witnessed at other stations. This supports local people's experience of increasing rainfall in the lower areas of Mustang.

Variability of river flow The trends in river flow during various hydrological seasons (dry pre-monsoon, monsoon, and post-monsoon) and extreme flows in a year (maximum and minimum discharges) have been studied at Kotagaon station, downstream of the KGRB, for the last 43 years. Although increasing trends are observed in the dry pre-monsoon and post-monsoon discharge, they are small in magnitude and statistically insignificant (based on Mann–Kendall test). However, the magnitude of these changes is expected to alter in the near future due to changing climate. There will be considerably less rain in the dry pre-monsoon and post-monsoon compared to monsoon season, and water in the KGRB will be largely contributed by snowmelt and/or sub-surface inflow into the river. An increasing trend in dry pre-monsoon and post-monsoon discharge indicates that melting of snow is occurring and that increasing water level is due to rising temperatures in the high mountains. This result supports the observation of people's perception of climate change and their experience of increasing water levels in the Kali Gandaki River.

3.3 Climate change impact assessment

This section briefly discusses the results of the assessment of the impact of climate change on water resources using the YHyM/BTOPMC model under 19 different plausible perturbed climatic scenarios consisting of several combinations of temperature and rainfall changes. The results of climatic perturbation analysis show that annual average discharge increases by 2.4, 3.7, and 5.7 % when temperature increases from the reference value by 1, 2, and 3 °C, respectively. Temperature rise also results in marked differences in maximum, minimum, and seasonal discharges in the monsoon and pre-monsoon seasons. Simulation under perturbed precipitation scenarios suggests that precipitation has a positive relationship with total annual and monsoon discharge. The increasing monsoon season discharge may be detrimental to the downstream areas of the basin. In addition, comparison of the river discharge under different combined scenarios of temperature and precipitation changes show that a maximum increase (18.3 %) is observed for the T+3 °C and P+10 % scenario and maximum decrease (−15.8 %) is observed for the T+1, P−10 % scenario. These results are in line with the people's perception of the increasing impacts of climate change on water resources and guides further plans for appropriate adaptation options to manage them. Details of the model set up, scenario formulation, and other specifics are available in Manandhar et al. (2012a).

3.4 Water situation analysis

People's perception of water-related issues is further evaluated through water situation analysis using WPI. The WPI framework, its components (*Resources* (*R*), *Access* (*A*), *Use* (*U*), *Environment* (*E*) and *Capacity* (*C*)), indicators, and variables used in this study are detailed in Manandhar et al. (2012c); this section briefly discusses the water poverty situation in the whole basin and in the mountainous Mustang district.

On a scale of 0 to 100, with 100 as the best situation and 0 as the worst or more extreme case of water poverty, the KGRB's WPI is calculated as 49.2. *R* and *A* components are in a better situation while the *C* (46.5), *E* (25.5) and *U* (13.3) components are fairly weak at the basin level. Hence, to improve the water poverty situation, we should prioritize in decreasing order of priority, the water use, environmental integrity, and social and economic capacity of people to manage water in the basin.

The WPI values over the different districts in the basin reveal variations in the water poverty situation throughout the basin; from a WPI value of 37.1 in Arghakhanchi, to 56.5 in Kaski. Taking the example of the Mustang district, the WPI is slightly lower (WPI=46.5) than of the basin as a whole (WPI=49.2). The Resource component scores less in the Mustang district compared to the basin, due to lower water availability and high variability of rainfall in this area. Access to water resources is better at the basin level, and seeks improvement in the district, mainly in terms of sanitation facilities. Similarly, performance of the Environment component is better in the basin than at the district level. However, the district level water (*U*=41.3) and the people's Capacity to manage water and related problems (*C*=53.5) is better than at the basin level. In addition to poor domestic water use, weak agricultural water use is mainly responsible for water poverty at both the district and basin level. Overall, the basin WPI is better than the district WPI. Above all, however, improving water use at both district and basin levels is essential. These results help those responsible for water resource management to focus on specific water resource problems while planning appropriate climate change adaptation options.

3.5 Identification and evaluation of possible adaptation options

An analysis of people's perception and observed hydro-climatic trends confirms the existence of climate change or variability with its associated impacts on water resources, which necessitates practical responses. Perception of water-related issues and their evaluation showed that limited domestic and agricultural water use are the major problems in the mountainous Mustang district of the KGRB. Although the climate change impacts assessment reveals that water availability will increase in the future, development of irrigation facilities is difficult due to complex topography, therefore, people must continue to deal with limited water and the vagaries of climate. Based on these consequences, possible adaptation options to address climate change-driven impacts on water resources in the agricultural and domestic water use sectors are reviewed and listed in Table 2. Between the two different water uses, agricultural water use accounts for the largest share, and is one of the major sources of income for people in Mustang. Therefore, seeking a plausible option for managing water resources in agriculture is crucial.

Among many possible adaptations, vegetables intercropping with apples are already one of the more popular adaptation options in Mustang. In the face of climate change, annual agricultural crops that fail to yield are simply lost investments, while many trees whose yields decrease during unfavorable climate will bloom and yield the following year, as a result of the robustness of tree species. Tree crop cultivation on agricultural lands is therefore important both for climate change mitigation and for adaptation. Temperature change has resulted into ecological shifts, which has already been witnessed among apple cultivations in the Kullu Valley of Northwestern India (Vedwan and Rhoades 2001), and predicted for Japan (Sugiura and Yokozawa 2004). Mustang is increasingly experiencing a temperature rise and erratic rainfall. Between 1981 and 2007, temperature indices at Jomsom station already showed statistically significant upward trends (Manandhar et al. 2012b). This temperature increase has resulted in a shifting of climatic suitability for crops in the region. In the case of apples, there is clear evidence of the unsuitability of apple cultivation at lower elevations, unlike in past years but optimum climate has expanded into the higher altitudes (Nepal Trust for Nature Conservation 2008; Manandhar et al. 2011). Therefore, incorporating apples into cultivable areas can be a potential adaptation option that is location- and context-specific.

Suitability of apple cultivation is further evaluated from physical, social, and economic perspectives using the land evaluation framework given by FAO (1976). Biophysical suitability assessment showed that 5.2, 39.8, 51.3, and 3.7 % areas are highly, moderately, marginally not suitable for apple cultivation, respectively. It is possible to expand apples into the uncultivated cultivable areas, intercropping with other crops. Economic suitability assessment confirms that apples intercropping with vegetables and cereals are more profitable than cereals or vegetables alone. Furthermore, the market situation in 2009/2010 reveals that there is still a high possibility of selling Mustang's apples in Nepalese markets. The social suitability assessment also shows that 77 % of households are willing to expand apple production, no social conflicts are recorded for apple cultivation, income

Table 2 Summary of possible adaptation options for mountainous region of the KGRB

Water use sector	Adaptation options
Agriculture	Livelihood diversification
	High efficiency irrigation systems
	Managing irrigation systems on a rotational basis
	Reliable seasonal, weather forecasts
	Crop insurance, social protection measures
	Farming adjustments (crop diversification—tree crop, vegetables, corn, etc…)
	Application of conservation practices
Domestic or household	Snow and rainwater harvesting
	Collection of water in community ponds

from apples has supported household income, and more than 50 % are satisfied with apple cultivation. From the optimistic results of biophysical, economic, and social suitability assessments, it is reasonable to support the cultivation of apple trees into cultivable areas of Mustang as a potential adaptation option for the mountain people against climate change. This adaption option can possibly help to reduce the impacts of climate change.

4 Conclusions

This study introduces an integrated framework for assessing the impacts of climate change on water resources and to evaluate potential adaptation options in a poorly gauged region. It includes three main steps: (1) documentation and analysis of people's perception of climate change or variability, their impacts, water-related issues, and adaptation; (2) evaluation of people's perception; and (3) responses to climate change (e.g., adaptation options). The study then applies the proposed framework to an assessment of climate change impacts on water resources and an evaluation of adaptation options in the KGRB as a case study. The study results show that local people of the mountainous Mustang district in the KGRB have awareness and a perception of climate change and variability, its impacts, and adaptation. Its evaluation through hydro-climatic trends analysis reveals increasing trends in yearly mean and pre-monsoon discharge in Kali Gandaki River, warming trends at higher altitudes, and erratic rainfall throughout the basin. Furthermore, evaluation of climate change impacts on water resources using various climatic perturbation scenarios shows increase in annual average discharge by 2.4, 3.7, and 5.7 % with temperature rises of 1, 2, and 3 °C, respectively. Perception of water-related issues and water situation analysis shows poor water use as a major cause of water poverty. Despite increasing water availability, increasing water use can be difficult due to the topographic constraints on irrigation development. Therefore, various adaptation options are identified and relevant options are evaluated. They demonstrate that incorporating apple trees into cultivable areas can be one plausible adaptation option, helping to cope with climate change impacts and water-related issues to some extent.

The integrated framework proposed in this paper is an attempt to demonstrate the need for better techniques to address climate change, its impacts, and adaptation options as a single package in data-poor regions. The framework attempts to bring together broader issues of water resource management in situations with limited data availability by linking social and physical aspects of climate change together. The results have demonstrated the framework's potential to better characterize local situations in terms of climate change impacts and adaptation, and help in water resource planning. The framework can be further improved by incorporating characterization of future climate and socio-economic conditions to assist in efficiently analyzing climate change and its impacts and evaluating adaptation options.

Acknowledgments We would like to express our sincere gratitude to MEXT and Global Centre of Excellence (GCOE) Program-University of Yamanashi for providing the opportunity to conduct this study.

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