Local effects of cryospheric change on agriculture and pasture in Trans Himalaya

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Abstract

Using the mixed method, combining spatial analytical and qualitative ecological oral history methods, this paper aims to examine the impacts of snow and ice over changes on local agriculture and thus on the livelihood of local people in the Trans Himalayan region. The results indicate very high inter-annual and intra-seasonal variability in timing and duration of average snow cover pattern in the region over the last decades. Substantially declining patterns of snow cover duration mainly in rangelands and crop production areas in the region has led to declining crop production and increasing rangeland degradation. Drying up of agriculture fields and significantly less water available in traditional irrigation canals following decline in snow and ice mass in their source area, led to widespread land abandonment in the villages having low capacity to harvest water from distant sources. Consequently, poor communities of dry Trans Himalayan region mainly dependent upon agro-pastoral subsistence production have been badly disadvantaged by ongoing changes in the Himalayan cryosphere.

Introduction

The Himalayan region, which is also popularly known as the “third pole” or “water tower of Asia”, has the largest snow and ice covered area outside the polar caps. The Himalayan cryosphere is the source of water for the innumerable rivers that flow across the Indo-Gangetic plains. About 1.5 billion people who live in these river basins are said to be directly or indirectly dependent upon the water from the Himalayan cryosphere. In the high altitude snow-fed and glacier-fed basins of the Himalayan region (Singh & Bengtsson, 2005), not only the water from the glacier but also from the melt of seasonal snow cover— that is winter snow accumulation and summer melt — is the main source of soil moisture and land surface hydrology. The agro-pastoral production, which has been the basis of livelihood throughout such a snow dominated region for centuries, is thus heavily dependent on water availability, mainly determined by cryospheric dynamics.

Regions like the Himalaya where supply of water is mainly dominated by melting snow or ice are considered to be greatly affected by current climate change. A very strong warming of the Himalayan region over the last decades has been indicated by recent studies, as reported that warming occurring at approximately 3 to 4 times greater than average global warming (Gautam *et al.*, 2010; Liu & Chen, 2000; Shrestha *et al.*, 1999; Solomon *et al.*, 2007; Xu *et al.*, 2009). Moreover, the warming rate has increased progressively with elevation and the warming in winter and spring is higher than in the summer and during the monsoon (Liu & Chen, 2000; Paudel, 2011; Shrestha*, et al.*, 1999). Precipitation in the region exhibits very high temporal and spatial variability, mainly forced by the East Asian and Indian monsoons (Bhutiyani *et al.*, 2010; Shrestha, 2000). Due to the orographic nature of monsoon rainfall, there is distinct variation in rainfall between the southern slope and the rain shadow areas or inner valley. The rain shadow areas of the region receive very low precipitation compared to the other adjacent areas. Studies show that the drier regions of the Himalaya are receiving less and less precipitation and thus making the region further drier following the combined effect of increasing temperature and declining precipitation, while the wetter region is experiencing more rainfall (Paudel, 2011; Piao *et al.*, 2010). There is also a general agreement that extreme precipitation events are likely to increase in the region following the current pattern of climate change. Reported such changes in precipitation, mainly winter precipitation (snowfall), along with the increasing temperature trend, not only affects the inter-seasonal and inter-annual pattern of the extent and the mass balance of snow covered and glacierized areas of Himalayan region but also significantly affects the local to regional land surface hydrology. Which, in turn, significantly affects the traditional agro-pastoral production system and thereby the livelihood of local people.

There could be three levels of impact due to change in cryosphere following the effects of climate change: i) global feedback effects, ii) downstream effects and iii) local effects (Erikson *et al.*, 2009). Since snow and ice cover play significant role within the global heat budget (Bates *et al.*, 2008; Berry, 1981; Lemke *et al.*, 2007), deglaciation, decline in permafrost and change in snow cover—which are also considered as the first order of impact of climate change on the cryosphere —in the Himalaya have significant global feedback effects to global warming. Snow and glacial melt associated with climate change can lead to changes in the hydrological regime including too much or too little water discharge to rivers and the glacier lake outburst flood (GLOF) causing significant downstream effects. The resulted downstream effect could be catastrophic flooding with serious damage to life, resources, property and infrastructure downstream. Local effects of cryospheric change associated with climate change include changes in local soil hydrology and consequent effects on crop and pasture production and incidences of cryogenic processes like avalanches, debris flows and rock glaciers and the consequent impacts. These impacts are directly related to the local livelihood and the sustainability of human systems in the region.

The Himalayan region is considered to be one of the most important data and research gap regions in the world in terms of assessing climate change. Though limited, researchers and policy makers in the region are primarily concerned with retreating glaciers, GLOF and their downstream effects; nevertheless, local effects of cryospheric change in the region is generally ignored. The primary goal of this paper is to examine the impacts of cryospheric changes in the local environment, mainly on agriculture and thus on the livelihood of local people in the Trans Himalayan region, the rain shadow of the great Himalaya. Primary attention here is given to the impacts on agriculture land use, crop and pasture production.

Study area

The high altitude Trans Himalayan region of Nepal is located between the Tibetan Plateau in the North and the greater Himalaya in the south. The region is characterized by the rain shadow of the greater Himalaya, scanty rainfall, cold and dry climate, high weather fluctuation, high wind, limited amount of cultivable land and a short growing season. Three Trans Himalayan valleys — Upper Mustang, Upper Manang and Nar-Phu of Mustang and Manang districts of Nepal — have been selected as test sites in this study (Figure 1). The study area is the headwater environment of the Marshyangdi and Kali Gandaki Rivers.

The region is characterized by a high warming trend (0.02° C/year, $p = 0.02$) over the last four decades. However, the upper Mustang —the driest region of the study area— has slightly declining temperature trends in pre-monsoon (Mar – May) and post-monsoon (Oct –

Nov) and warming in monsoon (Jun – Sep) and winter (Dec-Feb) season (Paudel & Andersen, 2010). The average annual precipitation in the region is less than 400 mm per year and have a significantly declining precipitation (-3.5 mm/year, p= 0.003) trend. The upper Mustang is the driest region, with a mean annual precipitation of 164 mm, and has very high inter-annual variability of precipitation (coefficient of variability of annual precipitation > 35%).

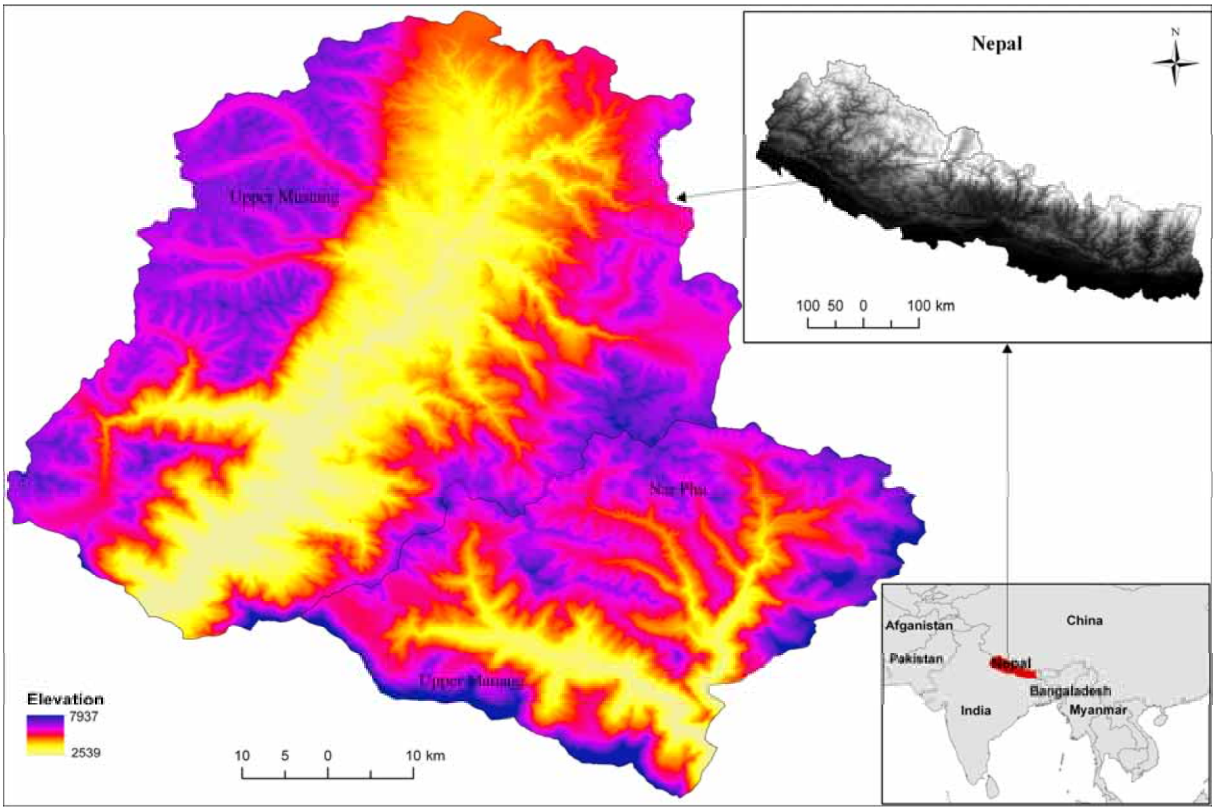

Figure 1: Location of study area: Upper Mustang in Mustang district and Upper Manang and Narphu valley in lManang district of Nepal.

Agro-pastoral production that is agriculture in the vicinity of settlement at valley floor, and transhumance pastoralism in the high altitude pastures is the dominant land use. Considering the remoteness and the soil characteristics, manure is the prerequisite for agriculture. On the other hand, considering the availability of winter forage, supplementary food from cropland is the prerequisite for sustaining livestock. Thus, close interdependence between livestock, rangeland, and crop land is the typical feature of Trans Himalayan agro-pastoralism, which has been the basis of local livelihood for centuries. Considering its cold, alpine semi-arid to arid climate, snow and glacier melt water is the main source of soil moisture for both agriculture and rangeland product. Moreover, availability of water in watering points (ponds, lakes, creeks and water spring) for livestock and herders is primarily determined by snow and glacier melt water, which ultimately determines the location of corral/encamp site as well as the spatial distribution of livestock pressure in rangeland.

Methodology

The study used a mixed method approach, that is use of both remote sensing/GIS analysis and ecological oral history methods. The study combined several distinct activities for data collection, analysis and interpretation. I used available Landsat images (1972 -2008), Moderate Resolution Imaging Spectrometer (MODIS) Terra 16-day composite normalized difference vegetation index (NDVI) images with 250 m spatial resolution (2000 -2009) and the global inventory modeling and mapping studies (GIMMS) NDVI images (1981 – 2006) with 8 km spatial resolution. I also used snow cover duration data (500m resolution), computed from both MNODIS Terra and Aqua daily snow cover products (2000 – 2010) with improved five step cloud removal methodology (Paudel & Andersen, 2011a). MODIS Landsat images, MODIS NDVI and GIMMS NDVI data were used to analyze changes in phenology, vegetation cover and above ground biomass production. To reduce the noise from MODIS and GIMMS NDVI products, iterative interpolation for cloud-free data reconstruction (IDR) method (Julien & Sobrino, 2010) was used. Similarly, simple NDVI ratio method was used to compute vegetation phenology metrics (White *et al.*, 1997). MODIS snow cover product and Landsat data were used to analyze snow cover dynamics in the region.

Field work was conducted during the summers of 2005, 2008 and 2009. During the field visits, data was collected by means of a detailed household survey (n = 214), semi structured interviews with key persons (n = 79) and seven group discussions. Questions included, among others, themes concerning the perception and experiences of changes in pattern and duration of snowfall, snow and glaciers, water availability and their impacts on agro-pastoral production. During group discussions, participatory mapping exercises were also carried out to mark the changes in snow and ice covered area in the region. During the transect walks, GPS observations data of abandoned field, dried up watering points and abandoned pasture corral site (*goth*) were also collected.

All available Instrumental precipitation and temperature data (1958 – 2009) were obtained from the Department of Hydrology and Meteorology (DHM)/Nepal Government. Whenever possible, I triangulated the data and results collected, interpreted or derived from different sources.

Results and discussions

Changes in the cryosphere

The analysis of MODIS snow data shows the slight decline in average annual snow covered area (-0.5 % yr^{-1}) and annual perennial snow and ice covered area (-1.7 ± 0.87%) during 2000-2010. Estimated snow and ice covered area based on Landsat images shows about 11% reduction in snow/ice covered area between March 1975 and May 2008. The region has experienced very high variability of snow cover duration, having the coefficient of variability of annual average snow cover duration > 50%, in the rangelands and in valley floor during the last decade. All cultivated fields and more than 80% rangelands below 4000 m in the study area have a significantly declining trend of annual snow cover duration. Monthly mean snow cover estimates showed maximum snow cover in February and least snow cover in December during the snow season (Oct – Apr) (Figure 2). The increasing events of early snow fall (in Oct) in high altitude zones and delayed in peak snow period over the last decade were the major reasons behind it. The observed significant delay, i.e. about 7 days y^{-1}, in peak snow accumulation day in the year in Manang and Mustang district over the last decade has been shown elsewhere (Paudel & Andersen, 2011a). Consequently, February/March have appeared as the peak snow months compared to January/February in the last decade. Meanwhile, oral history shows that December and January were the peak snow months about six decades ago.

People perceived a definitive reduction in snowfall and snow cover duration over time. More than 83% of the informants felt that the timing of the onset of snowfall delayed and about 98% of informants perceived significant advance in snowmelt period and decline in snow cover duration in the highland pasture. There is a general consensus among the informants of all study villages concerning the decline in intensity and duration of snowfall. Local people generally pronounce two reasons for declining snow accumulation (amount) and duration: first, shorter seasonal snow cover and second thaw out in advance of spring season.

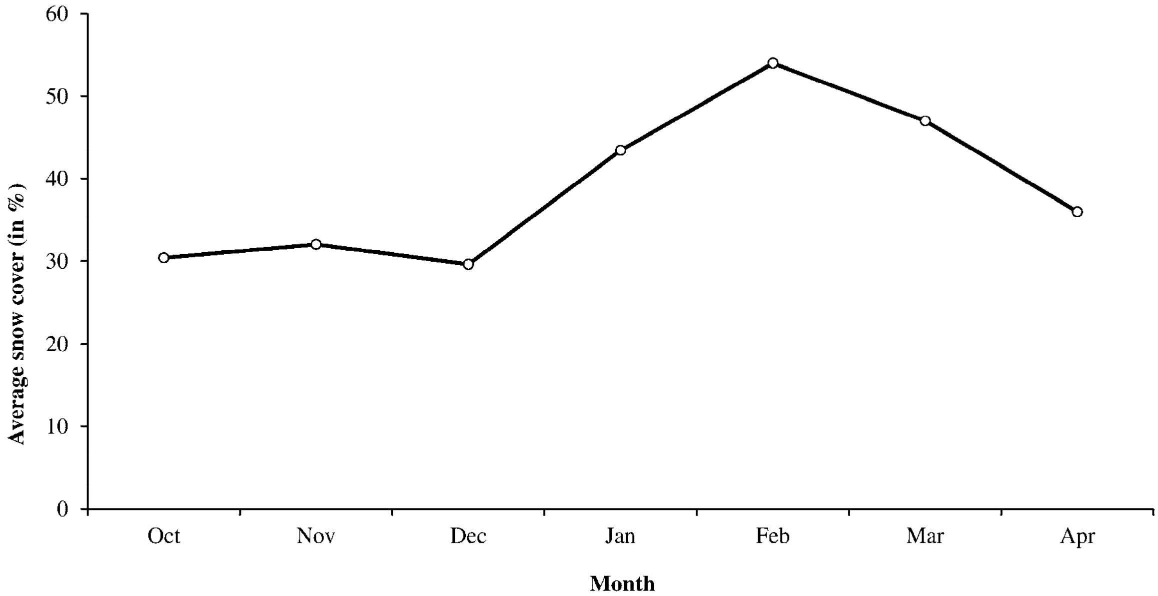

Figure 2 : Mean monthly snow cover area during snow season (2000 – 2010)

One of the significant observations experienced by local people is declining water resources following the decline in snow and glacier area. During group discussions and transect walks, informants frequently pointed to three types of evidence, which they experienced, of declining water resources: first, less water in the creek, which they used for irrigating fields; second, drying up of many watering points at highland pasture (e.g. in Ghami village alone drying up of 9 watering points were observed); and third, retreat of glaciers. Among others, the retreat of Gangapurna glacier in Upper Manang is one of the most pronounced by local people. The reconstructed retreat of Gangapurna glacier on the basis of terminal glacier and the historical photos by Aase *et al. (2010)* also shows a very high rate of glacier retreat over the last century in the region, which also validates the local perception.

Impact on agriculture and pasture

The immediate hydrological implication of decreasing snow and ice mass and the consequent less water in the study area is the recent abandonment of large swath of agricultural fields. The estimated land abandonment, based on an analysis of time series Landsat images along with GPS observation, participatory sketch maps of land abandonment and group discussions, in Upper Mustang is 39.5% of total cultivated land over the last four decades. While in some villages like in Chhoser in Upper Mustang I found about 50% of the cultivated land has been abandoned. In Ghiling village in Upper Mustang about 35% of the cultivated land has been abandoned mainly because of declining water for irrigation during the last four decades (Paudel & Andersen, Manuscript in preparation). In Upper Manang about 60% of the cultivated land has been abandoned over the last four decades (Aase*, et al.*, 2010; Paudel, 2006). However, most of the abandoned land in Upper Manang and in Chaile and Chhusang in Upper Mustang are primarily attributed to the massive exodus of people because of socio-economic reasons (For detail see Ghimire & Aase, 2007; Paudel, 2006; Paudel & Andersen, Manuscript in prep,; Rogers, 2004; van Spengen, 2000; von Fürer-Haimendorf, 1981).

The drying up and decrease in soil moisture in crop fields is another consequence of low water availability. According to local farmers, in the past they had to irrigate their fields twice a year in Upper Manang and three times a year in Upper Mustang but now they need to irrigate crop fields about 4 to 6 times. The declining water in irrigation creeks on the one hand and increased required frequency of irrigation on the other hand lead water scarcity and consequent land abandonment. This has also led to increased conflict over irrigation water in the villages in recent years.

Increasing high crop failure, mainly the production of barley and apples, following the changes in snowfall pattern and timing and duration of snow cover in the crop fields were frequently reported by local farmers during the interviews and group discussions. According to the farmers, incidences of substantially low barley production occurred mainly in the areas where barley is produced in high altitude fields and snow is the only source of moisture (because of lack of irrigation). Erratic pattern of snow fall and snow cover has also substantially affected the apple production in Mustang in recent years. The local perception is that the late snow affects the process of pollination indirectly due to the consequent low temperature and lack of early snow causes low soil moisture in many highland apple orchards, thereby leading to low apple production. Studies have also shown similar incidences of crop failure due to changes in snow pattern in other Trans Himalayan region (e.g. Vedwan & Rhoades, 2001). Farmers often remarked that the increasing incidence of pest and disease in crops are also associated with the changing pattern of snow along with temperature. However, a detailed study is needed to fully understand such ecological implications.

In pastures, the noticeable impact is drying up of watering points for livestock and source of water for herders. At this point, it would be worth mentioning that the capacity of communities to afford pipe and harvesting cost from distant sources, since in many cases nearer sources are already dried up, are also important factors to determine the adaptive capacity of local people against adverse effects of climate change. Villages highly advantaged by tourism and other socio-economic opportunities and which have strong claim making capacity to demand technology and support from national and district government are only able to harvest water from distant sources. Meanwhile others are compelled to abandon the site for pasture *goth*. The abandonment of watering points and pasture *goths* led to a high grazing pressure around the remaining place of livestock concentration, which consequently led to increasing rangeland degradation patches in the region (Paudel & Andersen, 2010).

Intensification of periglacial processes owing to change in snow cover pattern along with other temperature patterns caused an increase in degradation patches in south facing slope. Many such degraded patches are further accelerated by anthropogenic and erosion processes in the region (ibid.). This is also on par with the observation by Miehe (1996) in the alpine region of Karakorum.

The impact of snow cover changes on vegetation phenology, production and spatial distribution of vegetation species in the region (Paudel & Andersen, 2011b) as well as in other alpine regions (Grippa *et al.*, 2005; Miehe *et al.*, 2008; Wahren *et al.*, 2005; Walker *et al.*, 1993) is well documented. Participants in the study also reported significant impact of cryospheric changes on rangeland vegetation production and phenology.

The impacts of cryospheric change on local agriculture and livelihood is also largely the matter of contextual socio-economic environment and technological development. Contextual changes affect water and resource management. I observed that the villages having higher claim making capacity, for instances villages like Manang and Bhraka villages in Upper Manang and Jomsom, Lomanthang, Marpha, Kagbeni, Jharkot in Mustang, were able to harvest water from distant sources, replace old irrigation canals with modern pipes and manage water sources (cemented water tank and taps) in rangelands. However, villages primarily engaged in subsistence agro-pastoral production systems and with low claim making capacity like Ghiling in Upper Mustang are highly disadvantaged by ongoing climatic changes and resulted water scarcity. Thus, it is still the matter of water and resource management and the technology development in the region. This is in accordance with recent studies conducted in some villages in the region (Dannevig, 2007; Lamadrid, 2008).

Concluding remarks

This study attempts to trace the change in cryosphere and consequent impacts on local agriculture in the Trans Himalayan region of Nepal. The results indicate declining snow cover duration in agro-pastoral production areas and very high inter-annual and intra seasonal variability in timing and duration of snow cover patterns in the region. The study shows that snow cover dynamics have significant impacts on local livelihood of local people living in the snow dominated regions. The delay in peak snow period and erratic patterns of snow cover along with declining snow cover duration has led to a decline in soil moisture and less water in irrigation canals in the high altitude, cold, dry Himalayan region. This consequently leads to widespread land abandonment, declining crops and rangeland production and increase in rangeland degradation. The study concludes that the size of effect of cryospheric change on different regions and communities equally depends on the socio-economic factors such as human choice of action, technology development, and socio-economic resilience. The analysis also shows that combining methods from different theoretical perspectives like spatial analytical analysis, local perception and ecological oral history as complementary to each other holds the potential to provide in-depth and more relevant understanding of global to regional environmental changes and consequent impacts on local livelihoods and adaptation strategies.

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