Draft

Climate Change in Nepal:
Changes in precipitation dynamics, flow, livelihoods and adaptive actions

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The Stage

Nepal's geography has unique features. As the crow flies, about 150 kms from north to south the country covers about six geological and climatic belts varying in altitude from above 8,000 m to just 95 msl (mean sea level): the Tibetan plateau, the high Himalaya, the midland hills, the Mahabharat Lekh (range), the Chure and the Tarai. In addition the presence of valleys and terraces in between further confirms its uniqueness. Indeed the landscape of Nepal covers 118 ecosystems, with 75 vegetation types and 35 forest types. In this paper we refer to this landscape as the Himalayan mountain system (HMS). Broadly HMS consists of three ecological zones: high mountains (35% of Nepal's area), middle mountains (42% of total area), and the lower altitude Chure/Tarai range (23% of total area).

Land-locked, Nepal is one of the poorest countries in the world (per capita income of US$ 472). Of the country's 30 million population 25% lives below the poverty line which varies across geographic location, caste and gender. Poverty is higher in rural areas (35%) compared to urban areas (10%) and particularly severe in the mountains. Almost 66 % of the population is dependent on agriculture, and the agriculture sector contributes 35% to the GDP. These features suggest that Nepal is a country with "development deficit": access to drinking water, basic health, energy, education, transportation services is poor, and historical, social, and geo-political factors impose constraints on improving them. Climate change has added a new layer of stress. The impact of global warming will lead to impacts on Nepal with its many snow, glaciers, regional hydrological systems and their sub processes as the climate system becomes more unpredictable due to increase in average global temperature.

Climate Change Scenarios

Existing trend affirmed by studies suggests temperature rise and prolonged dry spells in Nepal. For example, from 1975 to 2006 maximum temperature in Nepal showed an increase of 1.80^{o}C (Shrestha *et. al*, 1999, Baidya *et al*., 2008). Recent modeling exercise indicates an increase in temperature over Nepal that ranges between 0.5-2.0^{o}C in 2030 (NCVST, 2009). NCVST used 15 General Circulation Models (GCMs) to develop temperature and precipitation scenarios for 2030, 2060, and 2090. The multi-model mean of forecasted temperature increase by the study for 2030s is 1.4 ^{o} C, rising to 3.0-6.3^{o} C, with a multi-model mean of 4.7 ^{o} C, by the 2090s (NCVST, 2009). Nepal's NAPA (2010) also suggests that days and nights are likely to be become warmer than in the past. Specifically GCM results suggest,

- extremely hot days (the hottest 5% of days in the period 1970-1999) are projected to increase by up to 55% by the 2060s and 70% by the 2090s.
- extremely hot nights (the hottest 5% of nights in the period 1970-1999) are projected to increase by up to 77% by the 2060s and 93% by the 2090s

The increase in temperature is associated with observed direct indicators of change in the form, intensity and timing of precipitation. The arrival of monsoon rains this year is delayed while in 2005 and 2008 the winter rains failed. These trends are confirmed by local communities also. Farmers of Nepal and other South Asian countries suggest that precipitation patterns have indeed altered: the monsoon season starts later and its spatial distribution has changed. In addition instances of increased hail and decreased frost have been experienced in some areas. Scientific analysis of precipitation pattern show mixed results however. According to NCVST (2009) GCMs project a wide range of precipitation changes, especially in the monsoon: -14 to +40% by the 2030s increasing -52 to 135% by the 2090s.

While uncertainty in assessing precipitation is evident, other types of change are also underway. These changes point to upward shifting of agro-ecological belts and tree/snow lines, increased frequency and severity of flooding, depletion of local water sources, increasing risks of glacial lake outburst floods (GLOFs), the encroachment, and rapid growth and distribution of exotic species, change in flowering behaviour on some plant species and increased prevalence of diseases and pests observed on forest and food crop species. Erratic rainfall and rising temperatures leads to delayed planting, shortened growing seasons, withered crops and increased incidences of pest infestations and disease outbreaks. These changes and others like them ripple through local and regional hydrological systems and have implications not only for the functioning of drinking water, irrigation, hydropower and other water use systems but also in the sectors such as agriculture, livestock, health and tourism. How a system as complex as HMS will behave to anthropogenic warming is difficult to predict. Yet efforts must be made to do so because impacts will have major implications for the country's ability to meet its developmental goals.

Natural System: Interdependence and Disaggregation

The threat of climate change to HMS has implications that go beyond Nepal's administrative and political borders. The snow covered region of the HMS is also referred to as the "third pole" or the "water tower of Asia," containing vast stocks of water in the forms of snow and ice. The mountainous region of the HMS is the densely glaciated area in the world outside of the north and south poles. The interaction of South Asian Monsoon (SAM) and HMS give rise to high density of rivers (more than 6,000) all of which flow into the Ganga River. Nepal's glaciers, snow, and ice-melt waters feed more than 40% of Ganga's flow. Of the total population of 650 million who live in the Ganga basin, about 400 million live in Nepal, India (Bihar, Uttarakhanda, part of west Bengal) and Bangladesh.

The Ganga river basin is the most populous river basin in the world. The basin is shared by China, Nepal, India and Bangladesh. Within the Indian Union the Ganga River is shared by the states of Uttarakhanda, Uttar Pradesh, Bihar, West Bengal. Madhaya Pradesh, Jharkhand and Rajasthan and Himanchal Pradesh. The Ganga River receives flow from Himalayan region as well as from the southern rivers that originate in the Vindhya range. The rivers that flow into Ganga from the South such as Ton, Son and Chambal are rain-fed and do not receive any contribution from snow melt. Like the tributaries from the HMS, ~~flow from~~ these rivers contribute to groundwater recharge of the aquifer systems of Ganga plain which remain as major source of drinking and irrigation of the dependent population. Because the Himalayan region and its foothills receive higher precipitation in the form of rainfall and snow, their hydrological characteristic is different from the southern rivers. The rivers from the HMS contribute to groundwater recharge of the aquifers in Ganga Plain. Even in the HMS not all rivers receive flow from snow melt. Thus not everyone is directly dependent on water sources derived from the melting snow.

Clearly climate change induced vulnerabilities will be different on these two types of natural water resource systems and the population dependent on them. In the following sections we will classify these rivers of HMS as snow-fed and non-snow fed rivers while presenting preliminary estimates of the population dependent on each. While this is true, it is difficult to disaggregate population dependent on snow fed rivers and those dependent on non-snow fed and other types of water sources such as groundwater. In the case of Nepal we ~~very~~ preliminarily assume that 18 northern district of Nepal[1] along the snow capped mountains range and their population (10% of Nepal's 2010 projected) are directly dependent on water from snow melt. In addition, we assume that people living along the river courses in districts other than the eighteen and in the Tarai are direct dependents. We estimate this additional population to be 25% of Nepal's population. Thus 35% of Nepal's population will be affected by change dynamics of snow system while 65% remain at risk due to changes in non-snow dependent systems. This estimate is based on many assumptions and must be used only as an indication.

It is clear thus that hazard types will be different in the case of the two. This will be useful starting point to assess the notion of resilience depletion in the wake of climate change and to take corrective measures. Thompson (1994) has suggested that building resilience has to be conceived along with technological flexibility and sustainable development. In some setting and regions, where a household has asset base, diversified income source and access to basic drinking water and food, other institutions such as NGOs, government departments, banking system and communications (Moench and Dixit, 2004) threats that will deplete resilience can be coped with easily (Thomson, 1994). This may not be feasible in many other cases. Middle income households in an urban region may be able to deal with depleting drinking water sources by buying water from private vendors at higher prices. In mid hills of Nepal that face increasing water scarcity due to depletion such option is not viable at all. A more realistic and distributed approach to resilience planning and building adaptive capacity will be needed.

Impacts and vulnerability

The impact of climate change on snow ice, glaciers and rivers has five implications on water based livelihoods. One, direct impact will be on tourism-based livelihood. The snow covered region of the HMS is an abode of global attraction supporting tourism. In 2010, 610,000 tourists visited Nepal. In the fiscal year 2004/2005 the amount of foreign exchange earnings from tourism sector was ~~is~~ 10,464 million rupees (Economic survey of Nepal, 2006). It is estimated that the tourist industry, directly and indirectly, employs 42% of total working population in Nepal.[2] In the mountainous region the most popular destinations are Everest region, Annapurna region, Langtang region and Dolpo region. Annapurna region is recognized as the major tourist destination where about 70,000 tourists visit annually.[3] Similar numbers of tourists visit the Everest region. Melting snow may detrimentally affect tourism and lead to a loss of employment for people dependent on tourism in the medium and long term.

The second implication is that the depletion of local water sources fed by snow melt in the high mountain regions will affect the~~ir~~ drinking water systems and local agriculture dependent on those flows. Nepal's high mountain regions occupy an area of 22,077 km^2 and hold a population of 1,687,859 (CBS, 2001). The livelihood of majority of the population here are dependent on use of natural resource base. They also graze yak, grow potatoes, barley, buckwheat and millet and trade crossing the mountains. They work as high altitude porters, guides, cooks and other occupations in the tourism industry. Changing climate dynamics with implications on drinking water systems and irrigation systems will affect health and local food systems. Both will result is resilience depletion.

The third implication in the high mountains is increased risks of GLOFs. Higher rates of ice and snow melt will increase the potential of glacial lake breaches with catastrophic consequences in the immediate downstream reaches. The Koshi River Basin, the Gandaki River Basin, the Karnali River Basin and the Mahakali River Basin contain 1062, 338, 907 and 16 lakes respectively (Bajracharya *et al,* 2004). Mool *et al* (2001) suggests that about 21 glacial lakes may have become critically hazardous. In 1984, Dig Tsho was breached when a large avalanche slid into it. Two hours afterward, the flood reached a peak ~~of~~ discharge of 1500 m^3/s. The event transported four million cubic metres of sediment down the Dudh Koshi River. It destroyed a 500 kW hydroelectricity project, 14 bridges, 30 houses and farmland worth around US$ four million. Three years earlier, the breach of Zhangzangbo Lake killed four people and damaged the China-Nepal Friendship Bridge on the northern border as well as seven other bridges, a hydropower plant, Arniko Highway and 51 houses. In 1985 a large avalanche triggered GLOF at Dig Tsho. The breach of Tam Pokhari in 1998 caused another devastating GLOF: two persons were killed, six bridges were destroyed and arable land was washed away. Losses were estimated at around Nepali Rs. 150 million. In 1997, the Tsho Rolpa in Dolakha District reached a critical stage. To mitigate the chances of its breaching, a spillway was constructed by Nepal's Department of Hydrology and Meteorology (DHM) with support from the Dutch government. This temporary solution, which involved constructing a trapezoidal channel, is expected to lower the water level by three meters in two years and thereby reduce the risk of breach of the lake. The impacts of GLOFs are localized loss. The regional risks are increased sedimentation in rivers that can alter their hydraulic characteristics and depletion of storage volume due to increased sediment inflow into a reservoir. Nepal has not built any reservoir in the river stretches that face GLOF risks. The only reservoir is constructed in the rain-fed Kulekhani River whose capacity was grossly reduced by massive sedimentation triggered by an unprecedented cloudburst in 1993.

The fourth implication is related to changes in regional hydrological systems as snow dynamics alters. The consequences will ripple through the region's social and economic systems that depend on flows from snow as mentioned above. Two questions emerge: what is the contribution of snow melt to the regional water budget and how will climate change alter this dynamics? Assessment is difficult because knowledge of the rate of snow and glacier melt due to climate change is uncertain. The estimates of the rates of contribution of glacier melt from rivers of Nepal to the annual flow of Ganga River range from 2 to 20 percent.[4] The mountainous snow hydrology is poorly researched and there are limitations of ground truthing due to difficult terrain and harsh environment. The second question is how many people will be made vulnerable by these potential changes?

More realistic answers to these questions are needed and in-depth studies need to establish overall changes in the water budget and their linkages with the livelihood systems that support population in the dependent river basins. It is critical that such studies consider river sub-basins and watershed as units of analysis. Only such studies are capable of delivering disaggregated understandings ~~of~~ the impacts and help explore the systemic linkages among agriculture, industry, hydropower generation, vegetations including flora and fauna, human settlements and food security. Such studies will need to examine adaption measures that individuals, households and communities have been taking to meet these changes and the stresses these existing practices face. Since the context of climate is changing we need innovative methods to make periodic assessment to capture the changing context.

While the threat of changes in snow dynamics is real, it is clear that those living in Nepal's non-snow-fed rivers that originate in the Mahabharat and Chure ranges will be vulnerable to other types of hazards than changes in snow-melt dynamics. That is also true of the population in Uttar Pradesh and Bihar who live in the immediate downstream regions of these rivers. This is the fifth implication. The challenges of these rivers and catchments involve depleting local water sources and increasing dry spells. These changes directly affect drinking water systems as discharges of sources that are tapped to feed these systems through community based units are ~~is~~ lowered. Altered rainfall pattern would change flow dynamics and may result in high surface runoff, reduced infiltration and low base flow with serious consequences on farmer-managed and agency built irrigation systems. Changes in flow dynamics also imply risks to hydropower systems of all types. These impacts become manifested through inter-linked systems, for example when a hydropower system generates lower energy than designed due to altered hydrological behavior that climate change is likely to bring. In such case, vulnerabilities will be transferred to a much larger population.

In the mid hills climate change may increase instances of frequent and high intensity rainfall as well as decrease in the number of rainy days. These events can exacerbate occurrence of landslides and mass wasting processes that can directly lead to loss of lives, infrastructures, agriculture and local asset base. These events can disrupt roads, highways and other communication systems affecting mobility and flow of information. Nepal's mid hills also experience floods caused by breach of temporary landslides creating a dam blocking a river. High intensity cloudburst acts as triggers of such events locally known as *bishyari.* The result is likely to be overall resilience depletion.

Adaptive Responses

This paper has presented a brief account of the differences between snow-fed and non snow-fed rivers of Nepal as they relate to climate change impacts. It attempts to link the risks to the questions regarding approaches to reduce climate change induced vulnerabilities. The discussion suggests that the problems are part of the Himalayan complexity that is seeing fundamental shifts in system functions as a consequence of changes in individual parameters or aggregate changes in multiple parameters (Moench, 2006). How does one disaggregate the driver of climate change from other drivers of change is an important question but without clear answer because chains of causality involving multiple factors are hard to trace, identify and prove (Moench, 2006). Because baseline assumptions regarding the natural system, in our case, the climatic and hydrological systems of the Himalayan region, no longer remain valid, any approach at resilience building must take note of the following factors.

Assessing climate change vulnerabilities: The focus should be on developing a systematic approach to locating areas that are vulnerable, and identification of marginalised and disadvantaged groups most exposed to the impacts of climate change within that area. That is only part of the story. This method should also assess how institutions constrain or support adaptation. Cost effectiveness of the approach must be considered by exploring the capacity of the local community in terms of human resources, finances, and knowledge.

Focus on iteration: Adaptation, or resilience-building, is not an end in itself, but a continuous process. Strategies should be continually revised in order to gain new insights on vulnerabilities, and priority areas must be assessed and reassessed in order to take appropriate and effective actions. Iteration and shared learning processes are important.

Building synergy between planned and autonomous adaptation: The stresses from climate change will emerge when changes ripple through interlinked systems to specific areas and people who live in those areas. But in the Himalayan region the science continues to remain poorly understood and impact cannot be attributed to causes. Part of the problem also emanates from limitations of modeling and the science of scenarios development. Given this limitation how does one devise planned adaptation response is an important question.

Managing within Uncertainty: The knowledge of building capacity for adaptation to climate change is emerging and uncertainties continue to increase. Uncertainty does not mean that there is no need for adaptation. We must devise approaches/methods to work within uncertainty. That requires recourse to flexible pathways that seek incremental solutions.

Build capacity: The process should focus on building capacity of different actors at the national, sub-national and local levels that cross geographic, administrative and sectoral silos. A number of key questions must be addressed: What is resilience planning for climate change? What is adaptive capacity? The needs for capacity building will be dynamic and ever-changing as there are no readymade solutions. Any research programme must suit the local condition under which local governments, communities and NGOs, work. Community groups and local government actors need to improve their capacity to plan, organize and respond to the emerging challenges in their locality. Local governments play an increasingly important role in enabling both planned and autonomous adaptation at local levels. However central government and the private sector also need support to respond to the constraints that climate change is likely to bring about. The role of these actors is more critical in creating system as planned adaptive measures that can enable autonomous adaptive responses.

Shared learning: Building adaptive capacity requires sharing, learning and sufficient time. Climate change is a global process, but local conditions shape its impacts, so practitioners must integrate local and global knowledge in order to identify effective responses. Sufficient time is needed to gather and/or produce reliable climate data, to share this information with different end users, and to build relationships for planning and implementing programme to prevent resilience depletion. Shared learning should be embedded in the adaptive capacity building process so as to transcend barriers and initiate collaboration across sectors and scales as well as help synthesise and simplify scientific knowledge for dissemination such synthesis into local contexts.

Concluding comments

The above discussions suggest that Himalayan hydrological systems have embedded uncertainty (Dixit and Moench, 2006) and as a result we will not be able to say precisely what the future will hold for us. Fundamental challenges confront us as we attempt to adapt to climate change impacts. In their seminal work that explored the challenges of policy making in the Himalayan region in the backdrop of deforestation Thomson *et al* (1986) have expressed "doubts that uncertainty could be dispelled, and thus should be accepted as part of Himalayan system." The nature of climate change processes in the region endorses the postulation that uncertainty would continue to remain embedded. That there is uncertainty does not mean that we should not make efforts to minimize uncertainty as Ives (2004) argues, "an attempt must be made to reduce the level of uncertainty as far as possible." Better understanding of Himalayan climate system is clearly a case in point.

The key to reducing uncertainty lie in understanding the level of risks, incentives and capacity that different sections of society have to adapt to them. We need approaches that recognize the dominance of extreme events and ways to better adapt to them. Inherent to this capacity is our ability to take cognizance of processes involved in data collection, synthesis and use in a climate changed future. In this future, the basic worldview on which hydrological science exists would cease to remain valid as historically collected data would not be able to predict the future. This fact require us to makes a conceptual shift. Dixit and Moench (2006) suggests, "instead of stating we need to know sediment loads to design a structure we should ask, how can we design structures that are not affected by sediment load?. This is a very different way of formulating problem and is a necessary point of departure in dealing with adaptation to climate change.

Notes

[1] These districts are Taplejung, Sankhuwasava, Solukhumbu, Dolkha, Sindhupalchowk, Rasuwa, Gorkha, Kaski, Manag, Mustang, Dolpa, Jumla, Kalikot, Humla, Mugu, Bajhang, Bajura and Darchula.

[2] www.mapsofworld.com/nepal/tourism

[3] *www.nepalguidetrek.com*

[4] According to Sharma (1977) glacial melt accounts for about 10 per cent of the average flow of Nepali rivers. More recent estimate suggest that snowmelt from the Himalaya provides about 9% of Ganga's River flow (Jianchu *et al.,* 2007; Barnett *et al.,* 2005). A study by Alford et al. (2010) indicates that in Nepal the glacier contribution to sub-

basin stream flow varies from approximately 20% in the Budhi Gandaki Basin to approximately 2% in the Likhu Khola Basin, averaging approximately 10% across nine basins. This discharge volume represents approximately 4% of the total mean annual estimated volume of 200 billion cubic meters for the rivers flowing out of Nepal. See Malone (2010) for details.

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