Impacts of Climate Change on the Water and Ecological Security of the Himalayan Mountains and need for Adaptation through South-South Exchange

Madhav Karki, Pradeep Mool, and Arun Shrestha; ICIMOD, Kathmandu

Abstract

Mountain regions have experienced above-average warming in the 20th century with significant implications for both mountain environments and vast population dependent on the ecosystems services derived from them. In the Himalayas, progressive warming at higher altitudes has been three to five times greater than the global average. The most noticeable impact of climate change has been the rapid recession of glaciers in both the Himalayas and Andes. The retreat of glaciers in Nepal Himalayas has resulted in formation of dangerous glacial lakes. In the Andes, receding glaciers has reduced water supply to Peru's dry coastline by up to 12 percent. Degradation of permafrost and reduction of snow and ice caps are seen across the cryosphere leading to changes in land surface and water availability for mountain and downstream communities. Of particular concern to both the continents is the impact on dry season river flows affecting the supply of water to vast population. Policy and decision makers in both Asia and Latin America should recognise that there is an inherent interlinkage between the climatic and non-climatic drivers influencing the freshwater resources. Although it is extremely difficult to predict the type of changes, it can be safely assumed that both the regions face increased risks of devastating floods, extreme events and longer droughts. These negative scenarios will have regional and global implications in terms of hunger, food insecurity, health hazards and conflicts warranting urgent attention by global community. Building resilient communities and adaptive development and management of vital sectors especially water, agriculture, energy and ecosystem services are the only way to adapt to climate change.

1. Introduction and background:

The Hindu Kush-Himalaya (HKH) Mountains are rich in diversity of natural resources including abundance of water, have scenic landscape, extreme heights and slopes, fragile ecology and fertile valleys that provide a bundle of ecosystem goods and services. The HKH is the source of nine major river systems in Asia. It includes all or part of four global biodiversity hotspots, 330 important bird areas, two mega-diversity countries (India and China), and 60 eco-regions of which 12 are global 200 eco-regions. A total of 488 protected areas cover 39% of the total area. The region provides essential fresh water supply and ecosystem goods and services to more than 210 million upland people and to 1.3 billion downstream populations. The river basins are an important source of water, food, nutrition and energy. However, in recent years experts have been worried that climatic warming has been threatening these mountain ecosystems including water systems, especially high elevation biota that includes forest, agro-biodiversity, range and pasture ecosystems. The data collected from the eastern Himalayas show that there is a definite warming trend at higher altitudes and that areas at altitudes above 4,000m seem to be experiencing the greatest warming trend. The warming trend observed ranges from 0.01 to 0.06 ℃/yr (Shrestha, 1999)and the annual mean temperature is expected to increase by 3℃ by the middle of the century(Shrestha and Devkota, 2010) . The real issue of the ongoing and expected climatic changes is not the pace and magnitude of the changes that are happening but how the changes are affecting the ecosystem dynamics forcing species to migrate to cope. In response to fast rising temperatures and changing rainfall patterns, species are moving upslope into already occupied territory and are facing heavy competition, and many may not be able to adapt and eventually may face extinction (Eriksson et al., 2008).

Only a limited number of studies provide climatic scenarios of the Eastern Himalaya, especially on the situation with glacier melting and change in the ice mass. The projected temperatures are suggested to be about 3 °C warmer than the baseline by the middle of the century and about 4 °C warmer by the end of the century. Models project about 20% and 30% increases in the annual precipitation in the eastern Himalayas by the middle and the end of the century respectively. The projections are highly influenced by the emission scenarios and have some bias in projection, particularly in the case of precipitation

(Shrestha and Devkota 2010). The incidence and impact of aerosol (ABC) and black carbon mixed with green house gases of upper, especially glaciarised slopes is also becoming equally important in contributing to the melting of ice and snow. Climate change through various pathways is believed to impact water availability and water related hazards as compared to other factors.

2. Impact on the cryosphere

The Himalayas host a range of glaciers covering vast areas of snow and ice cover. The Himalayan cryospheric regions, especially those in eastern region are highly sensitive to climate change. In recent years, there have been several studies on monitoring and assessing the dynamics of glacier in the Himalayas. Overall, the evidence supporting the phenomenon has been conclusive enough to make glacial melting and retreat an important indicator for climate change. Evidences of glacial retreats have been found in Khumbu and Shorong Himal, (e.g. Kadota et al. 1997), Tamor River basin (Bajracharya et al 2007), Dhauligiri region (Fujita et al. 2001) etc in Nepal. Some of these studies indicate that the glacial retreat accelerated after the 1990's. Similar results were found for Tarina Glacier - a glacier in Bhutan associated with Tarina glacial lake and having calving terminus (Ageta et al. 2000). Karma et al. (2003) observed retreating trend in majority of 103 glaciers studied in Bhutan. It has to be noted here that majority of the studies on glacial dynamics rely on observation of terminus position. Terminus fluctuation does not provide complete information about the glacial behavior. There is not much study on glacial mass balance in the eastern Himalaya. There are some studies in Nepal Himalaya (AX010, Yala, Rikha Samba, Mira glaciers) and studies are for short durations or intermittently. Recently ICIMOD began studying seasonal variation in the snow cover in the Himalayas using MODIS data. The AR 4 mentions of 500,000 sq km of glaciated surface in the HKH region (IPCC 2007). However the most published area coverage is about 110,000 sq km. A recent detailed study by ICIMOD shows glaciated area coverage of 60,000 sq km (ICIMOD 2011 unpublished). This shows the lack of some of the most basic data related to Cryosphere.

3. Impact on hydrological regime

Changes in the precipitation pattern, shrinkage in snow cover and glacier and changes in the land cover in combination are likely to have impact on the hydrology of the river basins. Changes in stream flow and river discharge have important implications for water and flood management, irrigation, and water management planning. The change in the water availability, seasonality, and quantity can impact various sectors of development for example, hydropower, agriculture, drinking water supply and environmental flow. As most of the countries in the Himalayas are dependent on the monsoon rain for agricultural production a small shift or change in the water availability can produce a huge impact on the national economy. Agriculture is the dominant sector in almost all the countries in the region providing livelihood, income and employment (e.g., 79% of the population in Bhutan and 80% in Nepal are engaged in agriculture contributing around 30% to the national GDP (NPC, 2007). Hydropower is another important sector for countries like Bhutan and Nepal. Hydropower is the backbone of the Bhutanese economy as during the 8th Five Year Plan period, earnings from hydropower constituted 45% of the country's revenue (NAPA Bhutan, 2008). Fluctuations in the river flow will have impact on the hydropower production particularly during the lean periods when the flows in the rivers are highly dependent on the snow and glacier melt from upper catchments. In view of the changes in basin hydrology and rainfall patterns water supply situation is projected to worsen due to climate change. India, in its Climate Change strategy for example has set a goal of achieving 20% water use efficiency (NAPCC India, 2008). It is therefore pertinent to understand the current changes and make future projections based on solid data collected through robust research. There is a need to monitor the impacts through remote sensing tools, then measure them at representative sites, and model the future directions of the changes through modeling. New source of hazards and risks have to be measured and assessed so that proper adaptation and mitigation measures can be planned and implemented to reduce risks and manage disasters.

Per capita water availability is distributed unevenly between countries in the region. Bhutan has the highest per capita water availability with 43,379 m3 while Nepal has 8,542 m3, Bangladesh 8,418 m3 and India 1807 m3 (Cruz et al., 2007). The water availability per capita is likely to decrease due to climate change along with population growth and rising standards of living. Climate change is predicted to make dramatic impact on river flows though varying with regions and river basins (Eriksson et al. 2008). In the last few decades changes in the seasonality and the amount of water flow has been observed in some river systems in the Eastern Himalayas. The timing of the peak flood has been observed to be shifted in some parts of the Ganges Basin (Sharma and Shakya, 2005). The flood peak is found to shift from July to August based on analysis of 40 years of data (1965 to 2001) in the Bagmati catchment indicating the impact of climate change (Sharma and Shakya, 2005). Inter-seasonal, inter-annual, and spatial variability in rainfall has been observed during the past few decades across all of Asia (IPCC, 2008). Suggested increase in the frequency of extreme precipitation events could results in more floods, flash floods, landslide damming and subsequent outbursts. The impact of climate change on the melt water generation is also not well understood. Immerzeel et al. (2010) found Brahmaputra reasonably sensitive to climate change related impact on water availability, while this was not the case for the Ganges. Armstrong et al. (2009) also had presented similar results. However, the results tend to be impacted by the choice of models.

4. Impacts on water induced hazards

4.1 Glacial lake outburst flood

Formation and growth of glacial lakes is a phenomenon directly associated with glacial recession and mass wasting. ICIMOD using a combination of remote sensing images has published series of maps and in collaboration with its member countries has prepared an inventory of glaciers and glacial lakes of the region. The latest inventory for eastern Himalayas based on Landsat TM and ETM+ shows that there are about 4000 glacial lakes covering 181 km^2 in Ganges basin, and about 11000 glacial lakes covering 810 km^2 in Bhramaputra basin. There are 5389 glacial lakes in the eastern Himalayas (Nepal, Bhutan and North-Eastern India (including Sikkim and Arunanchal)) covering 192 km^2 area (Figure 1).

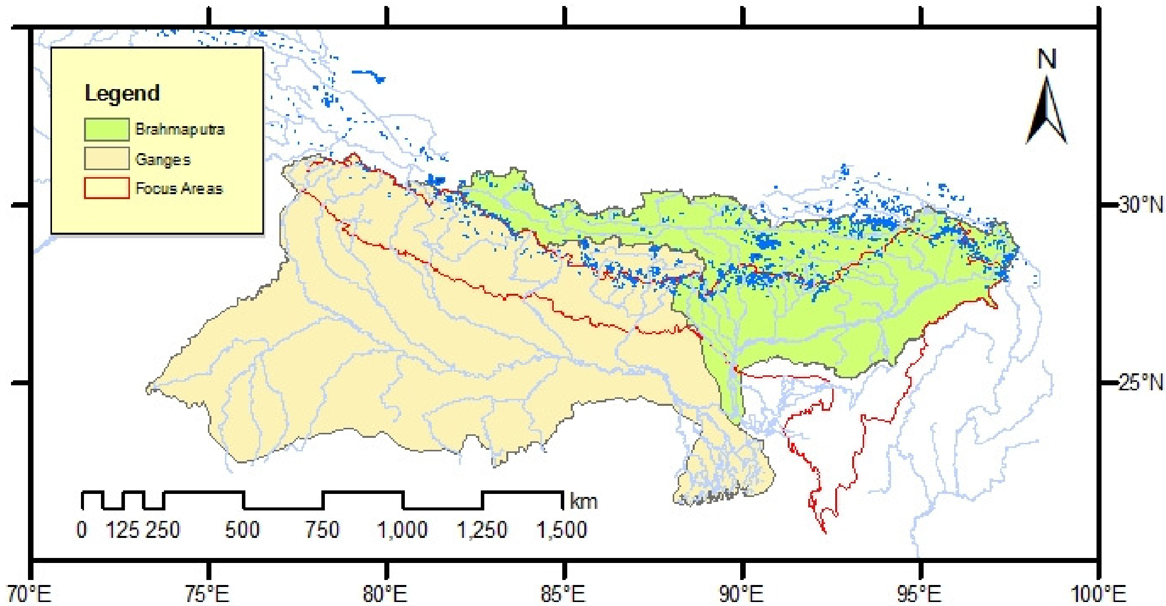

Figure 1: Map showing glacial lakes in Ganges basin and Bhramaputra basin. Data based on Landsat TM and ETM+ (ICIMOD 2010 unpublished)

Glacial lake outburst floods (GLOF) can result due to sudden release of lake water, which in turn is due failure of the lake damming moraine due to its internal instability or due to some external triggers. The surging flood water will often have tremendous energy to entrain large masses of loose material (boulders, gravel, sand, and clay, as well as any broken masonry or torn out trees) as it is propelled down-valley and cause huge damage to lives and livelihoods. Although evidence of 450 years old GLOF exists in Central Nepal (Carson 1985), GLOF frequency might increase under climate change scenario since the majority of the large pro-glacial lakes started forming after the middle of last century. There are some well-documented examples whereby lake outbursts have occurred Nepal and Bhutan including the events from Tibet AR (China) in recent years. There are about two dozen glacial lake outburst events recorded in history in Bhutan, the Pumqu (Arun) and Poiqu (Bhote-Sunkoshi) basins in Xizang (TAR China), and Nepal (Mool 1995; Mool et al. 2001a and 2001b; Yamada 1998; Bajracharya et al. 2008; Ives et al. 2010; ICIMOD 2011).

Some of the GLOFs have been of transboundary nature. Nepal has experienced 10 GLOF events which originated in Tibet, yet caused considerable damage in Nepalese territory. There were 34 GLOF events in Bhutan, Nepal and TAR/China the last one causing damage inside Nepal (Mool 1995; Mool et al. 2001a and 2001b; Yamada 1998a; Bajracharya et al. 2008). Twenty five lakes are considered as potential danger lakes in Bhutan, twenty one in Nepal out of which 10 are highly dangerous (Ives et.al 2010). These potential dangerous lakes can be subjected to prioritization based upon defined ranking criteria.

a. Floods and flash floods

Global warming, climate change and variability are expected to influence the precipitation regime (IPCC, 2008). There are many studies globally that have investigated the trends in stream flow (Milly et al. 2002, Ouarda et al. 1999). High regional differences and variability of the trends have been observed in the various basins studied. Increase in flood frequency and discharge have also been detected in some basins indicating increasing intensity of rainfall events during the recent years. Goswami et al. (2006)

analyzed 50years of Indian rainfall data from 1950 to 2000 and detected an increasing trend in the occurrence of heavy rainfall events with rainfall >100mm. The frequency of occurrence as well as intensity of heavy and very heavy rainfall events have highly significant increasing trend over Central India (Goswami et al. 2006) indicating increase in flood frequency and magnitude. Change in the magnitude, frequency and duration of the hydrologic extremes may be one of the most significant consequences of climate change (Cunderlink and Ouarrada, 2009, Sharma and Shakya, 2005). In the last decade serious and recurrent floods have been experienced in Bangladesh, Nepal and north east states of India during 2003, 2004, 2005 and 2007.

5. Need for augmenting water storage

One of the major concerns in relation to climate change in the Himalayan region is the reduction of snow and ice, which can reduce the region's fresh water storage capacity. More precipitation may fall as rain instead of snow, reducing ice accumulation. Precipitation may also increase in intensity with more falling over a shorter time. This results in a higher incidence and intensity of floods in the river basins. The higher proportion of runoff and reduction in ground water recharge will again affect natural storage capacity of water. When the consequences of climate change are superimposed on the high degree of intra-annual rainfall variability in the region, marked by a cycle of floods and droughts, it is clear that the threat of water scarcity could pose a serious challenge, especially to agriculture sector. For example, India has a skewed pattern of rainfall distribution, receiving 50%of its annual rainfall in just 15 days. A critical issue, then, is how to augment supply sources by storing part of the massive quantities of rain water in upper catchments so as to ensure supply for the entire year.

The Himalayan wetlands are a huge natural water storage infrastructure for freshwater which needs to be protected. These mountain slopes are natural reservoirs for surface and underground waters for the region. However, the availability (quantity, quality and time) of freshwaters is at risk due to a combination of factors including climate variability, socio-economic changes, poor infrastructure and lack of basin data and information for taking timely action. Degradation of wetlands in quality and in storage volume has been reported by various studies (Sharma et al. 2009; Yong Guowei et al. 2003; Shen Songping et al; 2005 as quoted in Zhang, 2009) and these have been attributed to climate change. Quantification of hydrological role of wetland is yet to be conducted over the river basins.

6. Key issues/gaps

From the foregoing discussions some key issues related to water and hazard sector of the region can be distilled out. The major gaps and key issues can be broadly divided into four groups: 1. climate change trends and projections;2. Impacts on cryosphere and its role; 3. GLOF hazards and risks; 4. Water storage needs and water availability; 5. Floods and flash floods management;

6.1 Climate change trends and projections

Climate change is an important driver but the role of other drivers such as migration, environment degradation, globalization etc. cannot be ignored. Information about contemporary trends and variabilities are sparse. This is mainly due to lack of adequate observational network especially in the higher elevation and general lack of sharing of existing data with other agencies and countries. Climate change projections are not of particular used for the scale of concern and specific basin wide projections are needed. In general, an increase in temperature is expected and in most areas, an increase or no-change in quantity of monsoon precipitation. The large uncertainties make these results of limited value for planning implementing adaptation measures.

6.2 Impacts on cryosphere

While impact on cryosphere is widely acknowledged and evidences are widespread presented, accurate information on cryosphreric mass changes is lacking. Information is even dreary when it comes to future cryospheric dynamics. The extent and dynamics of snow cover is still not well known and permafrost is largely ignored area. The role of cryosphere in the regional hydrology is often stressed, however, to date there is no convincing estimate on the contributions of various cryospheric components (glaciers, snow cover, and permafrost) on the hydrological regime and how the role varies with scale, e.g. from watershed to sub-basin to basin. Role of black carbon in the dynamics of cryosphere needs particular attention.

6.3 Glacial lake, formation, growth and outburst

Glacial lake genesis is generally taken is a rather simplistic way. GLOF hazard is often exaggerated, while comprehensive assessment of risk is frequently circumvented. Traditionally GLOF activities have been limited to mapping, inventorizing and identifying potentially dangerous lakes. Attempts to develop understanding on the origin and development of glacial lakes are inadequate. Wide-ranging hazard analysis including in-situ investigation of the potentially dangerous lakes is lacking and downstream impact and vulnerability assessment, such as by using dam break modeling is confined to a few lakes. Risk mitigation measures and early warning systems are limited to a handful of cases and a mechanism for transboundary risk assessment and early warning system is non-existent.

6.4 Water storage and water availability

The existing artificial water storage capacity of Himalayan countries in the region is much below the estimated requirement for maintaining minimum food security. Estimates of seasonal storage requirements are based on the food requirements of the population, the area of cultivated land, and the rainfall distribution pattern over the year. This implies that we need to view development of water storage capacity as an integral part of integrated water resources management, which is also considered by the IPCC to be an adaptive measure for climate change impacts.

HKH region has a good tradition of maintaining water availability by building water storage structures. Water ponds, tanks and seasonal water diversion canals have been the mainstay of ensuring water during part of the dry season in the region supporting livelihoods of the people relying on the water. However, knowledge on the role of major storage facilities and skills to design, build and maintain is poor. This is of utmost important for assessing the potentials for using natural wetlands/lakes/ponds for improving storage. Harnessing of glacial and snow melt water by storing them at high altitudes can not only enhance water storage capacities but also help generate more electricity. It is also necessary to study the support and contribution of traditional institutions for water storage management and rainwater harvesting to build resilience in them.

6.5 Floods and flash floods

Floods and flash flood is an important issue in the region. Major issue in this subject is the lack of proper forecasting and early warning systems. This is first and foremost true in the context of transboundary floods and flash floods. No or inadequate sharing of flood data and information across borders is a major impediment to an effective regional DRR strategy. As a result, forecasting and early warning systems are either absent or limited to national boundaries, resulting in poor lead time to give early warning notice for people to take precaution. The countries in region have varying capacities in their ability to forecast extreme weather events and resulting floods and flash floods and therefore an urgent need to institute regional co-operation framework in disaster risk reduction.

7 Building resilience and adaptation to Climate Change: the way forward to live with climate change and melting glaciers

From the above discussions, it is clear that climate change will be serious threat to lives and well being of the people in the Himalayan region. However the severity of the impact can be contained by taking early actions among them preparing community for disaster risk reduction and making development activities more resilient and adaptive to climate and other changes. For example `too much too little' water can be managed by improving the network of hydro meteorological stations in the upper mountains for example setting up of the automatic weather stations and building national and regional database so that early warning system of extreme events including GLOFs can notify communities downstream with adequate lead time to prepare. Similarly, systematic mapping of potential hazards due to emergence of GLOFs and landslides can help assess the risks to mountain and hilly settlements early on so that they can be either resettled or adequate risk mitigating or risk management efforts can be made to contain the potential disaster at mass scale. The key factors that need to be intervened are: vulnerability and adaptation which determines the resilience state or the coping capacity of the society. These two factors are also interdependent and collectively determine the extent to which climate change can impact the socio-economic sectors Figure 2.

The mountain communities for that matter all societies have been adapting to climate and other changes for centuries which is generally called `autonomous adaptation'. Recently, human induced climatic variability has pushed the pace to an extent that mountain people's traditional knowledge, ingenuity and wisdom are found inadequate and there is a need for new and rather robust knowledge to avoid `mal adaptation' . For example, it is well known that Peruvian government engineers have been working to avoid glacier disasters ever since 1951, when the national government established the Control Commission of Cordillera Blanca Lakes that is today known as the Glaciology and Hydrological Resources Unit. The glaciology office has been able to secure 34 dangerous glacial lakes by draining and containing glacial lakes before they produced outburst floods. These engineers working with local communities have judiciously combined traditional and modern engineering knowledge and have been able to prevent many GLOF disasters. They have jointly been able to save the cities of Huaraz in 1959, Huallanca in 1970, Carhuaz in 1991, Huaraz in 2003, and Carhuaz again in 2010 (Byers, 2011).

There are many examples of mountain societies adapting to climate related stresses by independently developed indigenously developed strategies and actions. While these strategies can enable them for coping the stresses to some extent, they do have limitations that need to be backstopped through technically sound planned adaptation measures. The Himalayan region has very few examples related to climate change impact adaptation, especially with GLOFS. The GLOF mitigation measures implemented in Nepal and Bhutan are few examples but these can be certainly improved through South-South sharing of experiences and learning.

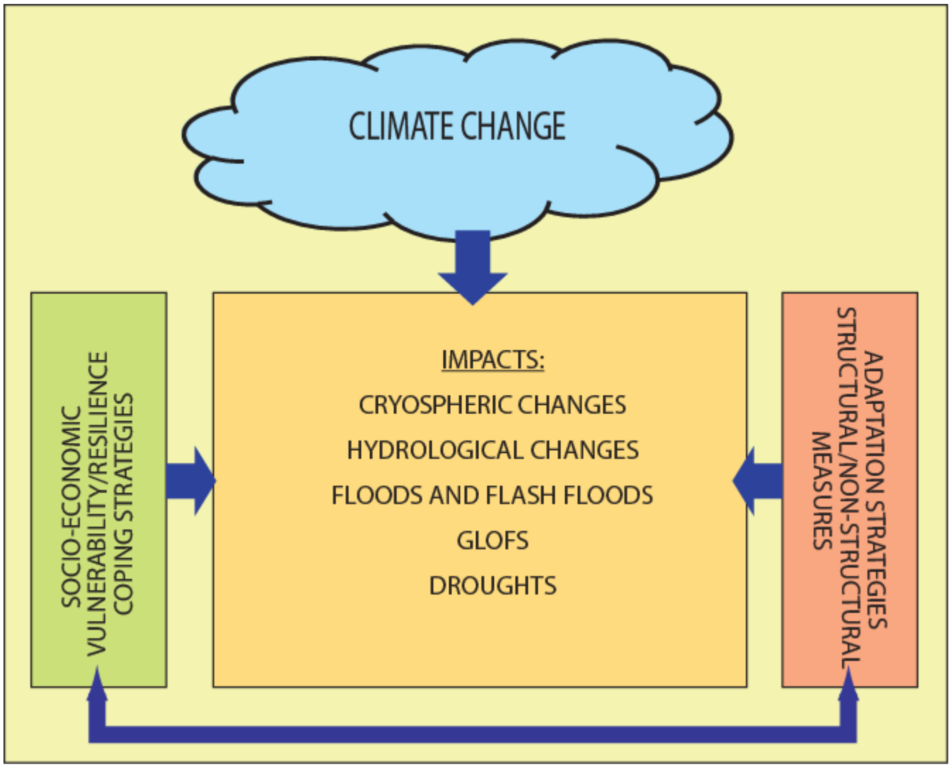

Figure 2: Conceptual framework of climate change impact and adaptation

7.1 Innovation in water storage capacity development:

It is possible to harness the huge potential of water storage development in the Himalayan region which can build resilience of water development infrastructure to climate change impacts. By pooling the available knowledge and expertise among different mountain countries, it may be feasible to manage the naturally occurring as well as human induced systems in the hydrosphere through initiatives such as wetlands conservation, watershed management including by building series of small rainwater storing and silt trapping ponds, tanks and dykes on the hills and mountains, as well as enhancing groundwater aquifer recharge, especially in mountain valleys and other urban areas. The zabo system of water storage and management by Naga society in Northeast India is well known fact (CSE, 2003). Improving property rights to forest and non-timber products and promoting good governance are the key aspects for achieving sustainable management of land, water and forests that can not only improve natural water storage capacity of mountain slopes but also improve the resilience of the agro-ecosystem through biodiversity enhancement and rise in crop productivity. Constructing large dammed reservoirs in the downstream plains is a further option. Depending on the geophysical characteristics of a specific location in the region, a combination of natural and artificial systems could be selected to meet the water needs of the community. It is necessary, however, to turn the natural storage options, including ponds, lakes and aquifers, from a passive source to a planned and active source of water storage.

A note recently prepared by Haeberli,et. al. 2008 has summarized the initiative in the Alps: "A recently started study in the Swiss Alps treats the questions where and when the lakes are likely to form, what their characteristics are (depth, volume, and moraine/bedrock) and how optimal and sustainable use can be made of them. To this end, a digital terrain model of the Swiss Alps 'without glaciers' (Linsbauer et al. 2009) was generated to map out sites, where future lakes could form. The investigations combine perspectives of Geosciences (deglaciation, landscape evolution, lake characteristics, natural hazards) with hydraulic/hydrological aspects (retention capacity, flood protection, hydropower potential, sediment balance, ecological runoff regimes) and economic/touristic considerations (costs, benefits, perception, added value).” Perhaps this is the way forward for Himalayan and Andean glaciers also.

8. Conclusion:

The implications of the climate change impacts to both the environment and development processes in the mountain slopes and downstream communities are fairly obvious. Rapidly increasing onset events and impacts demands a major shift to the way the critical ecosystem services including water, rangelands, biodiversity and forestry are managed. While the rampant poverty in the high lands require continuation of economic growth but the type of resource management needs to incorporate measures to build resilience and adaptation to deal with the impacts and contain the inevitable consequences. The Himalayan countries face a daunting set of tasks in building more resilient water, energy, agriculture and natural resources sectors to ensure their vital food, energy and ecological security for the people. There is also a need for greater understanding and responding to the threat of climate-induced migration. More than 60% of the HKH’s economically active population depends on agriculture for their livelihoods and any serious impact on this sector will trigger mass-scale shift in people’s habitats. A pro-growth, pro-poor and pro-mountain adaptation and sustainable development policies, programmes and ground-level actions are needed to ensure system (agricultural, biodiversity and water sector) sustainability including more targeted adaptive management programmes for enhancing conditions of ecosystem services as well as livelihoods diversification can improves community resilience and adaptation capacity. Incorporation of ecosystem and water management adaptation and mitigation financing and technology transfer mechanisms in the ongoing international climate change negotiations can open opportunities for sustainable or low-carbon growth under climate change constraints in the mountains. Mitigation strategies that support adaptation and development investments with climate change co-benefits should be favored for enhancing ecosystem services including water storage infrastructures in the global mountain systems which provide fresh water for billions of people living downstream. Considering that securing fresh water supply to close to 1.4 billion people of the region as well as maintaining water for environmental flow, this paper concludes that Himalayan countries are planning to adapt to climate change impacts and build resilience in water resources management efforts but they need international expertise, finance and above all knowledge.

References:

Ageta, Y; Iwata, S; Yabuki, H; Naito, N; Sakai, A; Narama, C; Karma, T. (2000) ‘Expansion of Glacier Lakes in Recent Decades in the Bhutan Himalayas’. In Debris-Covered Glaciers, Proceedings of a workshop held in Seattle, Washington, USA, September 2000, International Association of Hydrological Sciences (IAHS) Publ. No. 264, pp 165-175. Wallingford: IAHS Press

Ageta, Y; Naito, N; Nakawo, M; Fujita, K; Shakar, K; Pokhrel, AP; Wangda, D (2001) ‘Study Project on the Recent Rapid Shrinkage of Summer Accumulation Type Glaciers in the Himalayas, 1997-1999’. In Bull. Glacial. Research, 18: 45-49

Armstrong, R; Alford, D; Racoviteanu A (2009) Glaciers as Indicators of Climate Change - the special case of the high elevation glaciers of the Nepal Himalaya, In: Water Storage: A strategy for climate change adaptation in the Himalayas. Sustainable Mountain Development No. 56, ICIMOD, Winter 2009, pp. 14-16

Bajracharya, B, Shrestha, AB, & Rajbhandari, L (2007). Glacial Lake Outburst Floods in the Sagarmatha Region. Hazard Assessment Using GIS and Hydrodynamic Modeling. Mountain Research and Development, 27, 336-344.

Bajracharya, SR; Mool, PK; Shrestha, BR (2008) ‘Global climate change and melting of Himalayan glaciers.’ In Ranade, PS (ed) Melting glaciers and rising sea levels: Impacts and implications, pp.28-46. Hyderabad: Icfai University Press

Carson, B (1985) Erosion and sedimentation processes in the Nepalese Himalaya, Occasional paper No. 1. Kathmandu: ICIMOD

Cruz, RV; Harasawa, H; Lal, M; Wu, S; Anokhin, Y; Punsalmaa, B; Honda, Y; Jafari, M; Li, C; Ninh NH (2007) Asia. Climate chane 2007: Impacts, Adaptation and Vulnerability. Contribution of Worrking group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, M.L. Parry, O.F. Canziani, J.P. Palutikof, P.J. van der Linden and C.E. Hanson, Eds., Camridge University Press, Cambridge, UK, 469-506

Centre for Science and Environment (CSE) 2003.

Cunderlik, JM; Ouarda, TBMJ (2009) Trends in the timing and magnitude of floods in Canada. *J. Hydrology* 375: 471-480

Eriksson, M; Jianchu, X; Shrestha, AB; Vaidya, RA; Nepal, S; Sandstrom, K (2008*) The Changing Himalayas;* Impact of climate change on water resources and livelihoods in the greater Himalayas. Kathmandu: ICIMOD

Fujita, K; Nakazawa, F; Rana, B (2001). Glaciological observation on Rika Samba Glacier in Hidden Valley, Nepal Himalayas, 1998 and 1999. *Bulletin of Glaciological Research, 18*, 31-35.

Goswami, B; Venugopal, V; Sengupta, D; Madhusoodanan, M; Xavier, P (2006) Increasing trend of extreme rain events over india in a warming environment. Science 314 (5804): 1442–1445.

Haeberli, W (2008) Changing views of changing glaciers. In: Orlove, B; et al, Darkening Peaks: Glacier Retreat, Science, and Society. Berkeley, US, 23-32.

ICIMOD (2011) Glacial lakes and glacial lake outburst floods in Nepal. Kathmandu: ICIMOD

Ives, JD; Shrestha, RB; Mool, PK (2010) Formation of glacial lakes in the Hindu Kush-Himalayas and GLOF risk assessment. Kathmandu: ICIMOD

Immerzeel, W; Beek, L. V; Bierkens, M (2010). Climate Change Will Affect the Asian Water Towers. Science, 328, 1382-1385.

IPCC, 2008. Climate change and water. Intergovernmental panel and climate change, IPCC technical paper VI, 200pp

Kadota, T; Fujita, K; Seko, K; Kayastha, R B; Ageta, Y (1997). Monitoring and prediction of shrinkage of a small glacier in Nepal Himalaya. *Annals of Glaciology, 24*, 90-94.

Karma, T; Ageta, Y; Naito, N; Iwata, S; Yabuki, H (2003) ‘Glacier Distribution in the Himalayas and Glacier Shrinkage from 1963 to 1993 in the Bhutan Himalayas’. In Bull. Glaciological Research (Japanese Society of Snow and Ice), 20: 29-40

Kulkarni, AV; Narain, A (1990) ‘Remote sensing based glacier inventory in the Sikkim State scientific note’, Marine and Water Resources Division, Remote Sensing Applications Group Space Applications Centre, Ahmedabad 380053. SAC/RSA/RSAG-MWRD/SN/01/90.

Milly, PCD; Wetherald, RT; Dunne, KA; Delworth, TL (2002) Increasing risks of great floods in a changing climate. Nature 415: 514-517

Mool, PK (1995) ‘Glacier lake outburst floods in Nepal.’ Journal of Nepal Geological Society 11: 273-280

Mool, P, Bajracharya, SR, Joshi, SP (2001a). Inventory of glaciers, glacier lakes and glicial lake outburst floods, monitoring and early warning system in the Hindu Kush-Himalayan Region. Nepal (No. ISBN 92 9115 331 1). Kathmandu: ICIMOD/UNEP.

Mool, PK; Wangda, D; Bajracharya, SR; Kunzang, K; Gurung, DR; Joshi, SP; (2001b) Inventory of glaciers, glacial lakes, and glacial lake outburst floods: Monitoring and early warning systems in the Hindu Kush-Himalayan region – Bhutan. Kathmandu: ICIMOD

NAPA Bhutan (2008) Bhutan National Adaptation Programme of Action, RGOB

NAPCC India (2008) National Action Plan on Climate Change (NAPCC) 30th June 2008

NPC (2007): Three year interim plan. National Planning Commission, GON, Kathmandu, Nepal.

Ouardo, TBMJ; Cunderlik, J; St. Hilaire, A; Barbet, M; Brueneau, P; Bobee, B (2006) Data-based comparison of seasonality-based regional flood frequency methods. *J. Hydrology* 330: 329-339

Sharma, HS; Shakya, NM (2005) Hydrological changes and its impacts on water resources of Bagmati watershed, Nepal. *J. Hydrology* 327: 315-322

Shrestha, AB; Wake, CP; Mayewski, PA; Dibb, JE (1999) Maximum temperature trends in the Himalaya and its vicinity: an analysis based on temperature records from Nepal for the period 1971-94. J. Climate 12: 2775-2789

Shrestha, AB; Devkota, LP (2010) Climate change in the Eastern Himalayas: Observed trends and model projections; Climate change impact and vulnerability in the Eastern Himalayas – Technical report 1. Kathmandu; ICIMOD

Tshe-ring, K; Sharma, E; Chettri, N; Shrestha, A (eds) (2010) *Climate change vulnerability of mountain ecosystems in the eastern Himalayas*; Climate change impact and vulnerability in the Eastern Himalayas – Synthesis report. Kathmandu: ICIMOD

Vaidya RA (2009) The Role of Water Storage in Adaptation to climate Change in The HKH Region, Sustainable Mountain Development No 56, ICIMOD, Winter 2009: 10-*13*

Yamada, T (1998). *Monitoring of glacier lake and Its outburst floods in Nepal Himalaya*: Japanese society of snow and Ice, Monograph No. 1.

Zhang Xiaohong (2009). *Conservation of Peatlands in the HKH: Experiences from the Tibetan Plateau*. Paper presented at the Consultative Regional Workshop on the High Altitude Wetlands in the HKH,