

# Climate change implication for Hydropower development in Nepal Himalayan region

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## *Research Paper*

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#### **ABSTRACT**

The effects of Climate change on precipitation pattern and hydrological regime are the most critical to hydropower generation. The trends on changes, though not exactly quantified, are visualized to be heterogeneous over different ecological zones of Nepal. Certain areas especially higher Himalayas of Nepal are becoming increasingly susceptible to hydrological transformations caused by climate change. Changing pattern of temperature is more visible and clear than precipitation. Changes in evaporation rates, annual river discharge, seasonal and temporal offsets of hydrological patterns, extreme precipitation events, and increased glacial melt are the most pertinent climate change effect that has impacted hydroelectric generation. Erosion and transport pattern of sediment is directly influenced by the pattern of changes in precipitation and runoff. Warming affected glaciers not only to contribute more water but also to the development of GLOF hazards. Rivers from Himalaya are

enriched by snow and glaciers melt. Snow melt contribution varies monthly with temperature and solar radiation over the ablation part of the snow and glacier areas in the catchment. Assessment river basin indicated that the snow melt contribution could reach up to 40 % in basin upper Kaligandaki and 20% in Kosi basin. The worst scenarios as per the present projection are that future flow characteristics of snow fed rivers could appear to be like that of present pattern of non-snow fed rivers. The methodology of the study was based on research output made available as published literatures, various scientific studies' results and information from multiple sources that are focused on climate change vulnerability to water resources, especial focus on hydropower, are synthesized and integrated.

**KEY WORDS:** Climate change, River flows, Hydroelectric, Himalaya

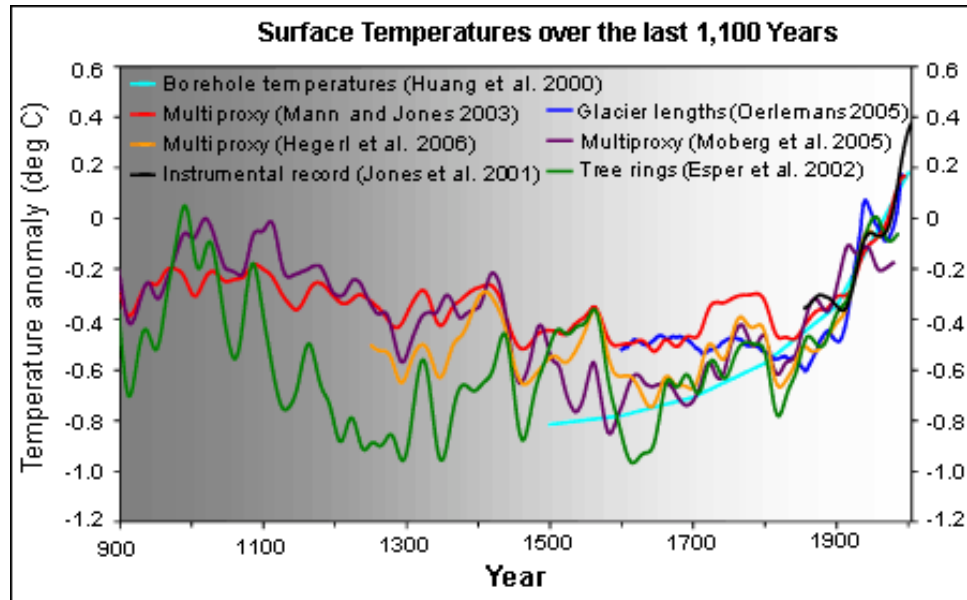
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#### **INTRODUCTION**

The inherent characteristic of climate is that it changes with time. The Holocene age began at the time of retreat of the continental ice sheets at the end of the last glaciations, which occurred at about ten thousands calendar years before present. The climate during the Holocene period appeared relatively stable but there were significant climate fluctuations during that period (Bard et al. 1997; Mayewski et al. 1997; deMenocal et al., 2000). The tropical region indicated a rapid warming from the early to mid Holocene followed by a relatively weak warming during the late Holocene. Temperature reconstructions derived from terrestrial vegetation (Huntley and Prentice 1988) and mountain glaciers (Porter and Orombelli 1985) as well as some observation (Crowley and North 1991) is interoperated as the Holocene Climatic Optimum with variability which

seemed around 2300 and 1000 years. The graph (Figure 1) provides reconstructions of surface temperature of Northern Hemisphere over the last 1,100 years (UK Met/IPCC 2007). Overall, the curves show a warming around 1000 AD followed by a long general cooling trend that continues until the early 1900s. Each curve illustrates a somewhat different history of temperature changes, with a range of uncertainties that tend to increase backward in time. The examination of various natural phenomena like natural variations, volcanic activity, and changes in solar activity, urban heat effects have been causing climate dynamics. Global average temperatures, calculated from networks of weather stations around the world, show a persistent warming trend and the warming trend is rapidly progressing (IPCC, 2007a). The Earth's average temperature has increased by 0.75 degree



**Figure 1.** Reconstructions of (Northern Hemisphere average or global average) surface temperature variations from six research teams (in different colour shades) along with the instrumental record of global average surface temperature (in black) (Source: IPCC).

**Table 1.** Projected change for temperature and precipitation under different scenario averaged over Central Himalayan region.

Scenario	Temperature Change ( degree C )			Precipitation Change (millimeter)		
	2020's	2050's	2080's	2020's	2050's	2080's
B1	1.1	1.9	2.5	28.4	49.3	64.1
A1B	1.3	2.6	3.7	33.7	84.9	121.0
A2	1.2	2.4	4.2	16.0	58.4	124.6

(Source: Karmacharya et al., 2007).

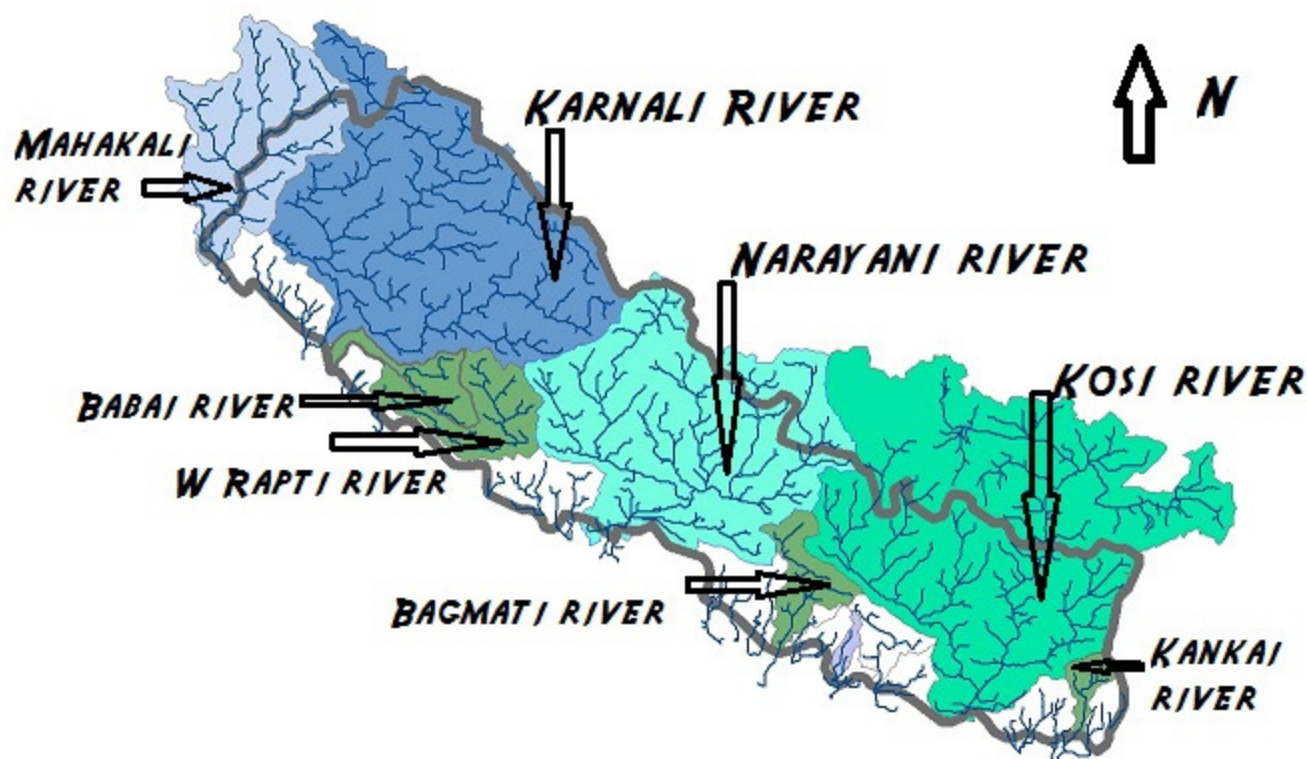
Celsius over the past 100 years (UK Met Office Had CRUT3 temperature record). Prediction on global change is made in mean annual air temperature, precipitation, specific humidity, annual runoff, and glaciations (IPCC, 2007b).

### Climate change in Nepal Himalaya

Temperature and precipitation observation history is not long enough to draw any conclusion on the nature of trend over Nepal Himalaya. Analysis carried out by some scientists/researchers had indicated the consistent and continuous warming after the mid-1970s. The warming rates follow the elevation gradient in the Himalayan region. It is also predicted that one degree temperature raise at sea level will correspond to two degree temperature raise in high altitude region like Himalaya (IPCC, 2001b). The IPCC AR4 has indicated that the warming in South Asia would be at least 2–4 degree Celsius by the end of the century (Christensen et al.

2007). Earlier study based on annual maximum temperature records of Nepal between 1977 and 1994 hinted an average warming by 0.06 degree Celsius per year (Shrestha et al., 1999). Later study indicated that the annual rate of temperature rise is 0.41 degree Celsius per decade and Nepal may experience warming on average by 3.5–4 degree Celsius in the projected scenarios at the end of the century (MOPE /UNEP, 2004).

Trend on precipitation was decreasing at the rate of 9.8 millimeter per decade in the month of April and May. A rising trend of precipitation was observed during monsoon seasons. Trends of monsoon onset and withdrawal from 21 years of data show that monsoon season is elongating. In case of trend of withdrawal of monsoon, it is not so distinct whereas trend of monsoon onset is quite distinct (MOPE /UNEP, 2004). Precipitation projection (Karmacharya et al., 2007) under low (B1), medium (A1B) and high (A1) GHG emission scenarios for 20's (2010-2030), 50's (2040-2060), 80's (2070-2090) showed increased precipitation in the entire Nepal (Table 1).



**Figure 2.** Location of three major rivers system, Kisi, Narayani and Karnali.

## RESEARCH OBJECTIVE AND METHODOLOGY

The climate change, warming of the atmosphere and ocean system is unequivocal and, their impacts are diverse. It has been concluded that recent warming had strongly affected natural biological systems (Rosenzweig *et al.* 2007). Water resources are heavily impacted from climate-related trends. It has been predicted that disparity will increase between wet and dry regions, as well as wet and dry seasons. Observed and projected impacts of climate change on river systems are mainly due to variable temperature and precipitation. (Kundzewicz *et al.*, 2007). Hydroelectricity is a renewable energy product which is widely used. This renewable hydro-energy potential, by nature, is distributed unequally and spatially in the globe (Lehner *et al.*, 2011). Rivers of Nepal Himalaya have high potential of hydroelectricity. The temporal and spatial variation in precipitation has directly related to hydropower production. Any alteration in precipitation patterns and hydrological regime is the most critical not only to ecosystem and livelihood but, also to hydroelectricity generation. In the current context of global warming, climate change has added challenges to hydropower developments and to its sustainability. So this study has kept the climate change in the centre of concern and focused on its implication to hydropower development in Nepal Himalaya.

The methodology included quantitative analysis and meta analysis. A meta-analysis refers to methods that focus on contrasting and combining results from different studies. Various reports and research papers especially, related to climate and hydropower is critically reviewed. Published flows records of major Nepalese rivers and precipitation trends by model studies are used and referred. Simple statistical tools were used to assess the river flow characteristics and trends. Major river systems of Nepal are categorized into snow fed and non snow fed rivers. Published data on observed river flows and climate data formed the base data. Flow characteristics and trends are quantitatively analyzed and assessed. The climate change effect in precipitation and temperature and its implication to hydropower is critically examined and concluded.

## NATURE OF HYDROGRAPH OF NEPALESE RIVERS

Nepal, a country of mountains and hills and sandwiched between India and China, lies in South Asia. Ecology and topography of Nepal consist of low, mid and high land regions that are run east-west (Figure 2). Mountains and hills occupy about 80 % of the total national land. The elevation differences favored for a variety of biomes from tropical savannas along the Indian border to montane

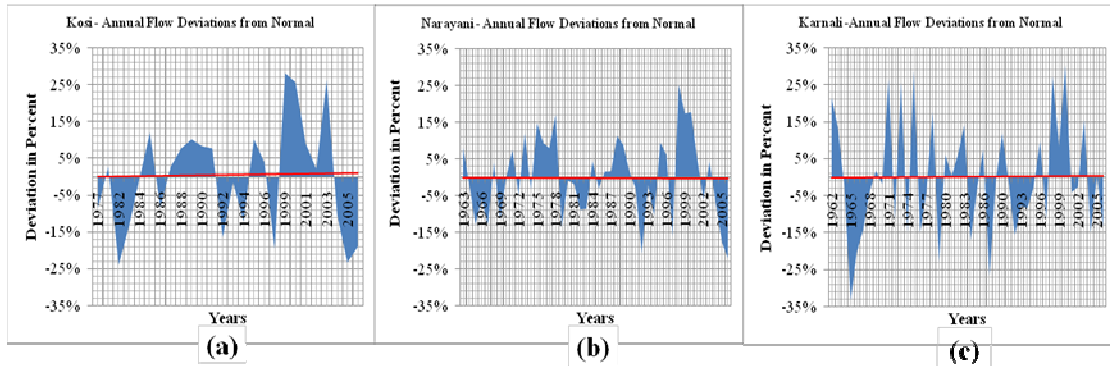


Figure 3. Trend in annual discharge of (a) Kosi, (b) Narayani and (c) Karnali river of Nepal.

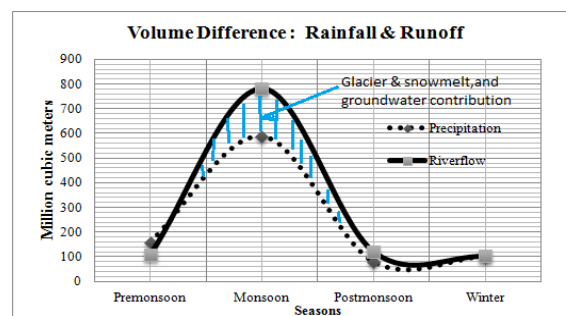


Figure 4. Annual runoff and rainfall volume.

grasslands and tundra with rock and ice at the highest elevations. Nepal's major rivers intersect north to south (Figure 2)

Based on published river flow data (DHM, 1998, 2006), trends on annual flows of perennial rivers are analyzed for two categories. Perennial rivers of Nepal are divided into two categories - snow fed and non-snow fed rivers (Figures 3 and 5). Non snow fed rivers ( Figure 5) are fed by rainfall only while snow fed rivers (Figure 3) get their sources at snow and glaciers while on their way, they also get input from rain fed rivers as well.

#### Nature of hydrographs of major snow fed rivers

Natures of hydrographs on three major river systems are assessed based on published data (DHM, 1998, 2006). There is a sign of increasing trend in Kosi river flows which drains eastern part of Nepal including a part of Tibet of China. But this trend is insignificant compared to the percent difference in annual mean to the long-term mean (normal) (Figure 3). Kosi flows found appreciable increase after 1998/99 and reached up to 30 percent increase in some years. Nature of flows in tributaries is of similar nature but amount of deviations varied. Similarly, Narayani and Karnali river flows showed a slight increasing trend. There is positive trend in Karnali river

flows. Karnali river showed relatively stable nature in compared to Kosi and Narayani river. Difference in annual means on Karnali river is about 20 percent. The contribution of snow and glacier melt water to annual flow of Kosi river at a station 'Chatara', from where river enters the plain area of Nepal Tarai, is about 8.46% (WWF 2009). A maximum monthly contribution of 22.52% is in May and a minimum monthly contribution of 1.86% is in January. 2.51% out of total 8.46% snow and glacier melt contribution is from Dudh Koshi sub-basin alone (WWF 2009).

Another assessment indicated that the snow melt contribution (Figure 4) could reach up to 40 % (Bhusal and Sagar 2011). The worst scenarios as per the present projection are that future flow characteristics of snow fed rivers could appear to be like that of present pattern of non-snow fed rivers. And the reduction in river flows in the basin could be up to 40 % if all snow dries up. However, the situation would be more miserable if temporal and spatial variations become wider due to climate changes in future.

#### Nature of hydrographs of non snow fed rivers

Among several non snow fed rivers (DHM, 2006, 2008), only three rivers were considered in this study (Figure 5).

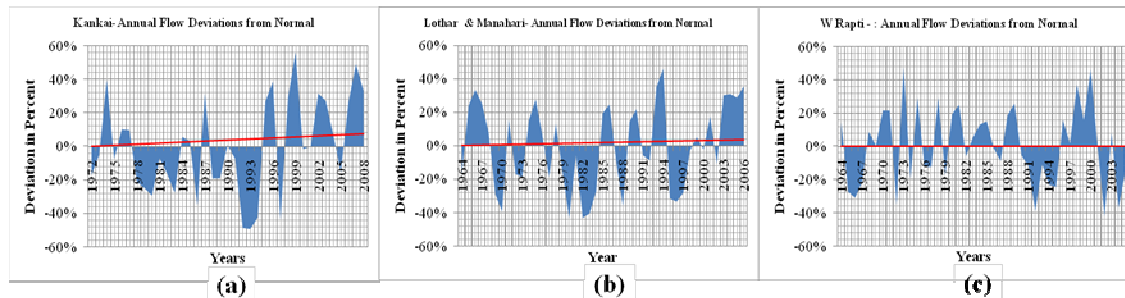


Figure 5. Trend in annual discharge of (a) Kankai, (b) Manahari and Lothar (c) West Rapti river.

The trend in Kankai which drains the eastern part of non snow covered areas is found at higher increasing trend than other in other rivers like Lothar-Manahari in the central region and West Rapti in the western region. In all three rivers, annual extremes are increasing where as there are decreasing trend in winter flows. The cause is the climate changes and anthropogenic activities.

### Climate change implication in hydropower

The most important climate change effects that impact hydropower are changes in precipitation and temperature (Figure 6). Parameters and processes that are visualized are presented in Figure 6 as a flow chart. Climate change not only leads to negative impacts to hydroelectric production but also favor improving hydroelectric potential (Blackshear et al., 2011; Izrael, 2007; IPCC 2007c).

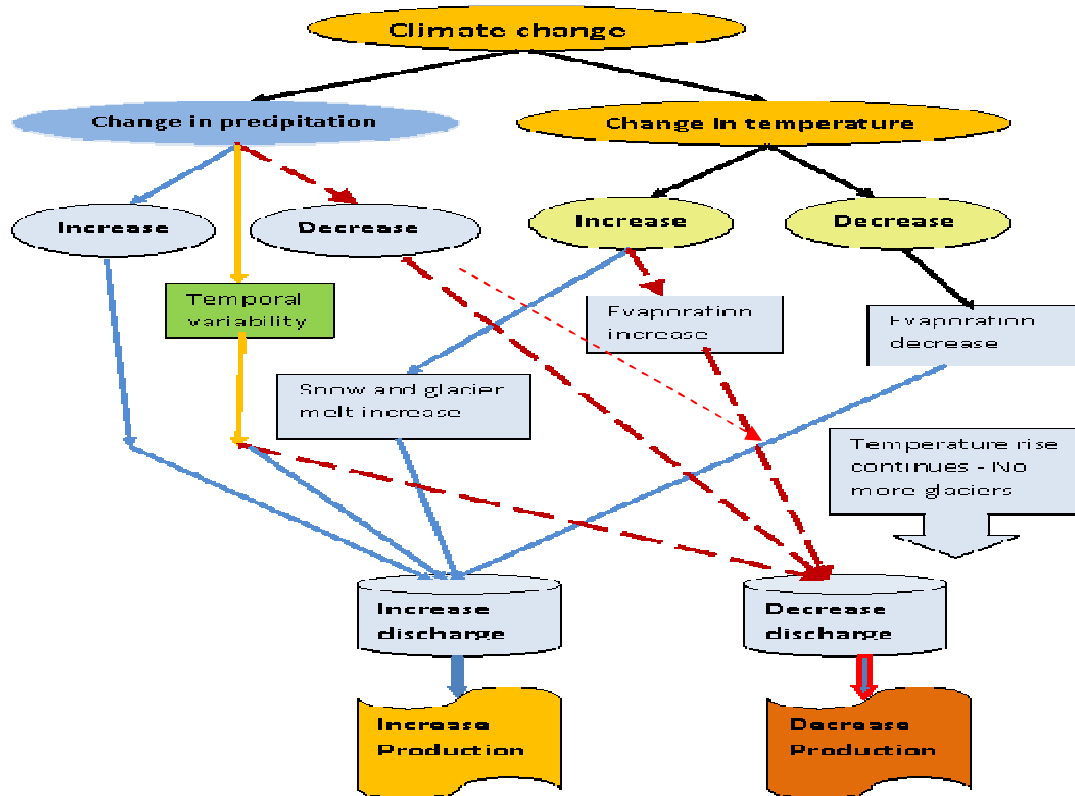
Some reservoirs have been shown to absorb Carbon dioxide at their surface, but most emit small amounts as water conveys carbon in the natural carbon cycle (Tremblay et al, 2005). High emissions of Methane gas have been recorded at shallow plateau-type tropical reservoirs where the natural carbon cycle is most productive (Frederic et al., 2006). Deep water reservoirs at similar low latitudes tend to exhibit lower emissions. Methane from natural floodplains and wetlands may be suppressed if they are inundated by a new reservoir since the methane is oxidized as it rises through the covering water column (Rosa et al., 2004, 2005). Methane formation in freshwater produces by-product carbon compounds (phenolic and humic acids) that effectively sequester the carbon involved (Rosa et al., 2004).

### Regional findings climate change effecting to hydropower

Rapidly melting glaciers in the Rocky, the Andes, and the Himalaya Mountain have been already changing respective hydrographs of the rivers they feed. Severe

storms caused by warming ocean temperatures have the capacity to threaten infrastructure, capacity and generation of hydropower over entire regions. Peribonka river watershed in Quebec, Canada predicted mean annual hydropower to decrease by 1.8 percent between 2010-2039 due to initial early peak flows and lack of summer precipitation) and subsequently increase by 9.3 percent and 18.3 percent during 2040-2069 and 2070-2099 respectively due to steadily increasing precipitation amounts (Minville et al., 2009). The prediction in increasing temperature and decreasing in rainfall on the Pacific and Northwest of the United States have likely to result about 40 percent loss in production by 2080 (Cullen et al., 2002). South America is expected to receive markedly less rainfall with increased intensity of the El Niño Southern Oscillation due to which significant decreases in stream outflow in parts of the Amazon and Tocantins river basins are expected (Izrael, 2007, Soito et al., 2011). There will decline in hydropower production correspondingly about 20 to 50 percent in counties like, Portugal, Spain, Ukraine, and Bulgaria (Lehner et al., 2005). In the short-term, glacially fed rivers in the Alps and Pyrenees will likely have increased in summer discharge. But the contribution of these retreating glaciers to river flow will decrease by 15 to 45 percent by the end of this century (Lehner et al., 2005) as many of such glaciers have diminished significantly (Huss, 2011). The Middle East's climatic variations are largely regulated by the North Atlantic Oscillation Pattern (NAO) (Turkes, 1996, Cullen et al., 2002). Similarly, climate models predict an average 10-20 percent decline in rainfall, resulting in the rivers of Botswana and Tunisia of Africa completely drying up (Mukheibir, 2007).

Increase in temperature is projected throughout the Asian-Pacific region which will increase evaporation and affect stream flows in countries like New Zealand and Philippines (Combalicer et al, 2010). Some studies predict increased precipitation in south-eastern Australia (Hughes, 2003) while other studies forecast a drier future on average (Chiew et al., 2011). Since the 1960s, the number of overall rainy days has decreased while the number of extreme precipitation events has increased in China (Qiu, 2010). South-Asia has already experienced



**Figure 6.** Flow chart of climate change effects.

disasters related to climate change which are often compounded by poor land-use practices. The 2010 floods in Pakistan affected over 20 million residents and inundated 62,000 square miles and the cause is also linked to monsoon rains intensified by climate change (Doyle, 2010).

### Climate change and hydropower in Nepal Himalayan rivers.

Hindukush region including Nepal face unique challenges as the climate continues changing (Shardul et al., 2003). Glacial location, variability in precipitation, lengthening of glacier melting time, frequent floods, and droughts are all symptoms of climate change that affect hydroelectric generation.

Climate controls river flow and glacier mass balance in the Himalayan region, and these vary considerably from west to east of Nepal Himalaya (Shrestha and Raju 2010; Xu et al., 2007). The slight increase in temperature paired with an increase in precipitation suggests that the evaporation rates of the region will decrease slightly. The overall increase in precipitation will provide more water to the rivers, increasing the potential for hydropower generation. South Asia's climate and hydrological cycles

are significantly impacted by the monsoon, which has already been altered by climate change (Science Daily, 2009). The monsoon delivers around 75 percent of the regions precipitation during roughly three months. Increase in the severity of rainfall events and storms results to the overall increased temporal variability in water supply (McNally, 2009).

The effect of recent climate changes on Nepal Himalayan river flows is noticed. The assessment is made on trends in three large snow fed rivers and some southern rivers. Preliminary trend analysis on observed records indicated that discharge trends are neither consistent nor significant in magnitude. It could be due to short record lengths and high inter-annual variability in discharge data. Among three large rivers, Karnali and Sapta Koshi show a decreasing trend, Narayani (Kali Gandaki), shows an increasing trend. Southern rivers do not show any trend. All of the three non snow-fed rivers examined here show a declining trend in discharge. The number of flood days and consecutive days of flood events appeared to be increasing. The peak melting season in the Himalayas coincides with the summer monsoon rainfall, which contribute to increased summer runoff and flood disasters (IPCC, 2001b). The increase in temperature would shift the snowline upward, which reduces the capacity of natural reservoir. Hydropower are rank significantly at higher risk than any other sector

because river flows are directly related to rising temperatures that have already been observed. The increasing temperature in the Himalayas will increase the glacial melt to increase river discharge for at least next some decades. However, once these glaciers diminish, there will be a decline in river discharges. Hydroelectric plants are highly dependent on predictable runoff patterns, Greater unreliability of dry season flows, in particular, poses potentially serious risks to hydro electric energy production in the lean season. In addition, an uncertainty in climate projections and lack of reliable hydrological records is a constraint for effective planning and operation of a hydropower.

Though intensified glacial melt increases the flow level of the rivers they feed but, rapid spring melting causes a shortage in late season flows when water is often critical for agriculture (Ives, (2011)). Such shortage also decreases to hydroelectricity production proportionally. Deglaciation in the Himalaya will also cause rapid growth of glacial lakes, which will increase the likelihood of glacial lake outburst floods. Glacier thinning and retreat in the Himalayas has resulted in the formation of new glacial lakes and the enlargement of existing lakes due to the accumulation of melt water behind loosely consolidated end moraine dams (Shrestha and Raju 2010). Such lakes are inherently unstable and when get burst, bring catastrophic damages (ICIMOD, 2011). The dark side of glacial lake outburst floods is that floods pose significant risk to hydropower infrastructures and facilities. Intense precipitation events, increased floods, landslides, and sedimentation (particularly during the monsoon) are expected to result from climate change. River sedimentation possesses high risk to Hydropower turbines, infrastructure and facilities.

## Conclusion

1. The effect of climate changes is visualized to be heterogeneous over different ecological zones of Nepal Himalaya. Certain areas especially higher hills of Nepal are becoming increasingly susceptible to hydrological transformations caused by climate change.

2. Changing pattern of temperature is more visible and clear than precipitation. Several studies find that there is change in rainfall and temperature pattern in specific areas which impinge significantly on the water resources, bio- diversity, agricultural systems, etc. Observed trends and variations in river flows and flow duration curves are visible which throw uncertainty to sustainable development of hydropower.

3. Considering the average environmental lapse rate of 6.5 degree Celsius /km, almost 20 % of the glaciated area above 5000 m is likely to be snow and glacier free area at an increase of air temperature by 1 degree

celsius. Two degree centigrade rise in temperature can lead a loss of almost 40 % of the area. Similarly, 3 degree Celsius and 4 degree Celsius rise in temperature can result in the loss of 58 % and 70 % of snow and glacier areas respectively in Nepal (MOPE /UNEP, 2004). Changes in snow and glaciated area are directly linked to runoff generation and hydropower potential. Temporal and spatial variability in precipitation and evaporation is additional effect to hydropower added by climate change. Such changes will cause an increase of hydropower generation for some years while the potential will decrease in longer time.

4. The slight increase in temperature paired with an increase in precipitation increases water volume snow and glaciated areas which can be tapped to produce more electricity for certain period of time.. But neither model is perfect to quantify the nature. Unsolved question is whether the rise in temperature is to be expected to be linear over the time; whether the present rate of temperature rise over the Himalayan region will continue or will show some discrepancies/stability in future.

5. Changes in future electricity production depend not only on the type and severity of climate alterations, but also on the structural characteristics of the system. Vulnerabilities vary on types and scales of hydropower whether it is run-of-river, reservoir, or pumped storage. Large-scale reservoir dams are able to regulate flow, produce electricity as desired but increase to evaporation losses.

6. The water storage might be a potential adaptation to response to increased variability in stream-flow and reduced dry season flows for sustainability of forecasted energy output from hydro projects. But there is also a risk of environmental objectives that might conflict with large storage projects. Dams could potentially exacerbate vulnerability to another potential impact if breached. Trans-boundary or regional dimension to certain impacts also demands need for regional coordinated strategies to cope with impacts of climate change.

7. The water storage might be a potential adaptation to response to increased variability in stream-flow and reduced dry season flows for sustainability of forecasted energy output from hydro projects. But there is also a risk of environmental objectives that might conflict with large storage projects. Dams could potentially exacerbate vulnerability to another potential impact if breached.

8. Above all, neither a river nor the sun and the atmosphere are constrained by manmade political boundaries. Climate change impact significantly spreads over local to global and vice versa. The other factors outside the science domain determining the hydropower generation are political, social and economic factors that

are unique to the region. Regional coordinated strategies are required to minimize impacts of climate change on Trans-boundary. Therefore the regional cooperation and collective efforts are vital in the development of hydropower and to cope with climate change.

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