Socio-economic Dimension of Snow and Glacier Melt in the Nepal Himalayas

Narayan P. Chaulagain

Abstract A mass balance analysis of the glaciers in the Nepal Himalayas has revealed that there have been accelerated retreats of glaciers causing widespread adverse impacts on the ecosystem, environment and economy in Nepal. The decreasing water storage in the mountain due to snow and glacier melt has created additional threats to already fragile and vulnerable mountain communities. The people and ecosystem in the mountain and foot hills are already under immense pressure from growing economic development. Climate change is putting additional pressure on the lives and livelihoods of the mountain people and on the ecosystem they depend upon. Studies have revealed that the majority of the glaciers in Nepal Himalayas are already retreating so rapidly that even without any further warming; most of them will disappear by the end of this century. This may result in decreased melt-water contribution to total water availability, particularly during dry seasons. The hydropower and irrigation sector, which are already under stress during non-monsoon seasons, will be badly affected. Though the annual decrease in per capita water availability due to warming may not be very much significant, the seasonal effect of the warming particularly during non-monsoon season is substantial. This will have major adverse impact to economy and society of Nepal. Particularly, the poor, marginalized, subsistence farmers and those living on natural system will face the largest adverse impact.

Keywords Glacier · Glacial lake outburst floods · Climate change · Socio-economy · Water resources

N.P. Chaulagain (✉)
ADAPT Nepal, Kathmandu, Nepal
e-mail: narayanchaulagain@gmail.com

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1 Introduction

Nepal has more than 6,000 rivers flowing from mountains to hills and plains. There are about 3,808 glaciers with a total area of 4,212 km^2 in Nepal Himalayas (ICIMOD 2011), which provide perennial flows for major river systems in Nepal. The contribution of snow and glacier melt water in these rivers, particularly during dry season is substantial. The temperature in Nepal is increasing faster in higher altitudes than in the lower ones, resulting in accelerated melting of glaciers, formation of glacial lakes in the mountain valleys and expansion of existing glacial lakes in Nepal Himalayas. This has resulted in increased risks of glacial lake outburst floods creating threats to people, property, infrastructures, livestock and ecosystem not only in the mountains but also far downstream in the hills and plains. Studies have suggested that glacial lake outburst floods in the Himalayas have occurred more frequently during the last 50 years (Mool et al. 2010).

Accelerated melting of snow and glaciers in the Himalayas has adversely affected the water storage capacity of the mountains. Decreased melt water contribution to the river flows particularly during non-monsoon season has negative impact on run-of-river hydropower, irrigation and even municipal water supply when the demand of water is relatively higher. The impacts of climate change are disproportionately distributed within the country among different communities and sectors of society. The poorer, marginalised, people of the high mountains, subsistence farmers are likely to suffer the earliest and the most (Jianchu et al. 2007). Mountain people have lived with and survived great hazards for thousands of years, but current rates of climate change have made them unable to cope with the changes by imposing severe and uncertain socioeconomic pressures.

2 Impacts on Water Availability

Increased temperature will not only affect the annual glacier mass balance, but also will change precipitation pattern, i.e. more rainfall and less snowfall. A study in the Langtang valley with a catchment area of 340 km^2 in central Nepal has shown that 1 °C rise in average temperature may reduce snow-to-rain ratio from 1.6 to 1.2 (Chaulagain 2009). Rainfall, unlike snowfall, will not be stored in the mountains, but will immediately be drained out from the basin resulting in less ground water recharge upstream and more floods downstream during the monsoon.

Majority of the glaciers in Nepal Himalayas are retreating at the rate higher than the glaciers elsewhere in the world, though the rate of retreat varies from glacier to glaciers. A sensitivity analysis of all the glaciers in Nepal Himalayas was done by using glacier mass balance model developed by Y. Ageta (Kadota and Ageta 1992; Naito et al. 2001) for the glacier AX010 in the eastern Himalayas and by applying the same empirical equation for the 24 glaciers in the Langtang Himalayas of the central Nepal. The analysis has shown that many of glaciers in

Nepal Himalayas will disappear by the end of this century in the Nepal Himalayas, if the melting of the glaciers will continue at the present rate. Likewise, the analysis has revealed that the current ice reserve of 480.6 km^3 in Nepal Himalayas will come down to 0.6 km^3 by 2,100, if the temperature will increase by 0.03 °C per year (see Fig. 1).

Such an accelerated decrease of ice reserve in Nepal Himalayas may result in the change of melt water contribution to the annual river flows. Currently, annual melt-water from the glaciers in the Nepal Himalayas is about 6 km^3 (see Fig. 2).

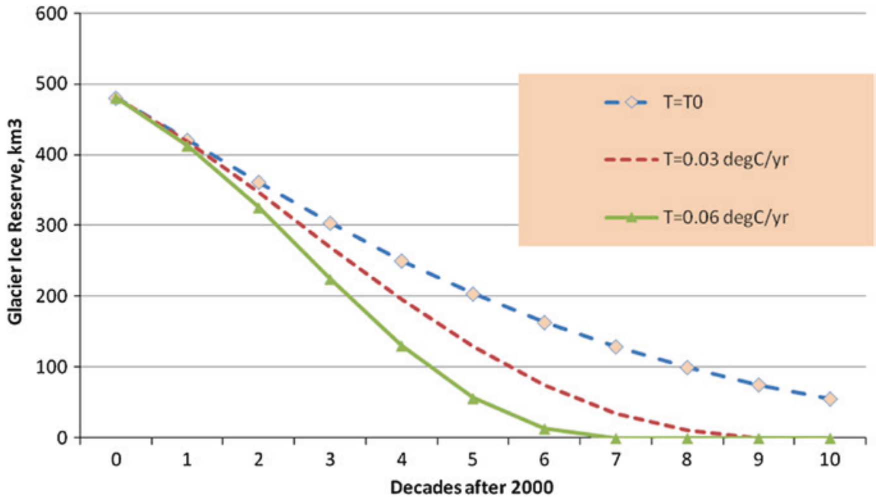

Fig. 1 Sensitivity of glacier ice reserve to warming. *Source* Modified after Chaulagain (2007)

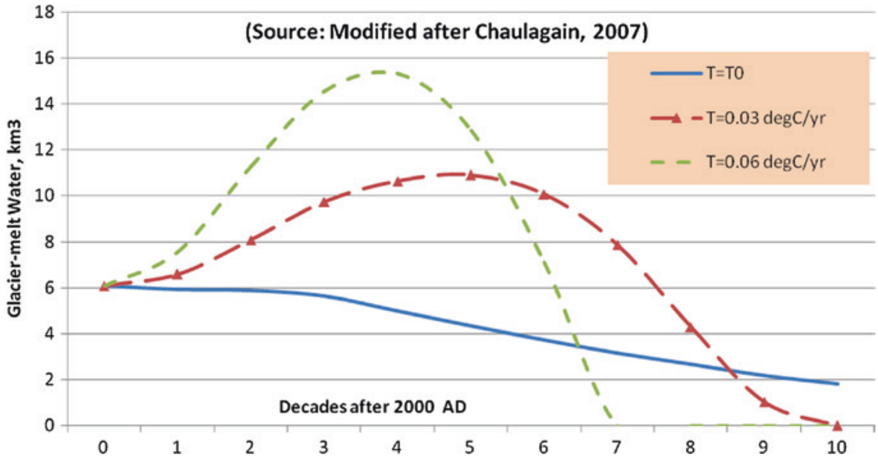

Fig. 2 Sensitivity of glacier-melt water to warming. *Source* Modified after Chaulagain (2007)

Water supplies stored in glaciers and snow cover are projected to decline in the course of the century, thus reducing water availability during warm and dry periods (Bates et al. 2008). The glacier-melt water contribution will initially rise with the rise in temperature and ultimately will go down after the contributing glaciers disappear (IPCC 2007). Decreasing glacier-melt water and disappearance of glaciers will ultimately change the hydrograph of the river system. The snow- and glacier-fed rivers will be converted into rain-fed ones. The monsoon streamflows including flood water will further increase and the dry season streamflows will further decrease. Currently, the snow and glacier-melt contributes to about 13 % of Nepal's total annual surface water. However, the snow and glacier-melt contribution is significant (up to 34 %) during April–May, when the demand for water is relatively higher.

3 Impacts on Hydropower Generation

Flood waters and river flows during monsoon seasons have a relatively less meaning for hydropower generation in the Nepalese context where majority of the hydropower plants are of the run-of-river type. As the glacier-melt water initially increases with increase in temperature and hydropower potential generally may increase as it largely depends on the lean season flows. Acharya (2011) after analyzing the observed flows of 6 major tributaries of Narayani River (i.e. Marsyangdi, BudhiGandaki, Trisuli, Kali Gandaki, Madi and Seti) for the period of 20–40 years has reported that there was a decreasing trend of the average flow during dry season (November–April). Nepal's hydropower generation generally follows the pattern of dry season flows (Chaulagain 2007). Over 90 % of Nepal's existing hydropower plants are the runoff river type which are generally designed based on the dry season flows.

These power plants have been already facing the problem of water shortages during dry seasons and generating only about 30 % of the total installed capacity in dry months. The problem will be further exacerbated during dry season by the reduced snow and glacier-melt contribution in the future. A similar analysis of Marsyangdi Hydro Electricity Plant (HEP) (69 MW) by using the outputs of the glacier mass balance model (Kadota and Ageta 1992; Naito et al. 2001) has revealed that out of the existing average annual electricity generation, about 27 % is contributed by snow and glacier melt water. Further increase in temperature will adversely affect the projected future energy generation of the hydropower station. The result of the sensitivity analysis of annual electricity generation is given in the Fig. 3.

As given in the Fig. 3, the future impact on the electricity generation by the hydropower plants largely depends on the rate of temperature increase. At the initial decades (e.g. till 2030), the electricity generation potential increase with the rate of temperature rise and then gradually goes down. The higher the rate of temperature increase in the future, the earlier the peak of the electricity generation potential of the hydropower plant will arrive.

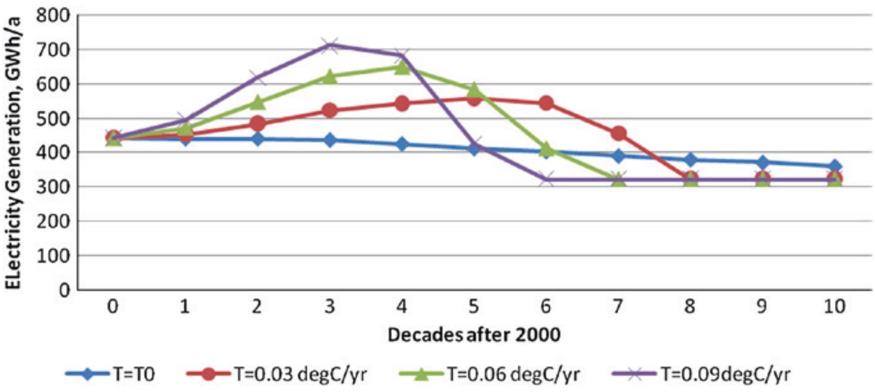

Fig. 3 Sensitivity of annual electricity generation of Marsyangdi HEP (2001–2100 AD)

4 Impacts on Irrigation and Agriculture

Increased temperature will result in increased evapo-transpiration leading to increased irrigation water demand, and decreased river flows. Studies have suggested that glacier-fed perennial rivers will be converted into rainfed seasonal rivers after the glaciers disappear. The ratio of maximum to minimum flows of rain-fed rivers is substantially higher than that of snow-fed rivers indicating a possible future re-distribution of water among months after glacier-fed rivers will become the rain-fed ones. Furthermore, increased temperatures will widen the gaps between the water supply and demand for irrigation. A water balance analysis of Bagmati river basin at Kathmandu Valley has shown that a one-degree rise in annual temperature may increase the water demand by 3.7 % and reduce the annual river flow by 1.5 % simultaneously, while a three-degree rise in annual temperature may increase the water demand by 11.2 % and reduce the annual river flow by 4.4 % (see Fig. 4).

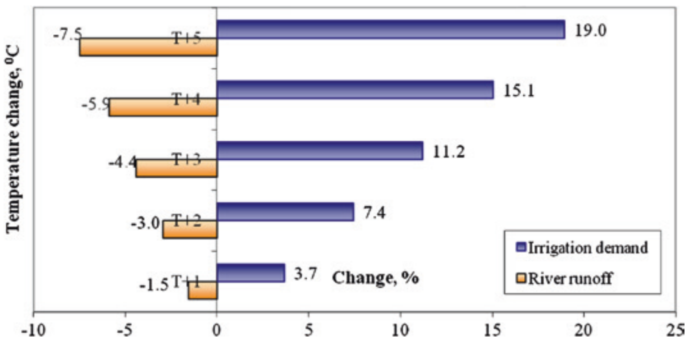

Fig. 4 Sensitivity of annual water balance situation at Kathmandu valley at chovar. *Source* Chaulagain (2007)

Due to monsoon dominated flow pattern, the Kathmandu valley in Bagmati river basin has already been facing water shortage during non-monsoon seasons though there is surplus water during monsoon. The increase in temperature will further worsen the situation of too much water during rainy season and too little of it during dry season. Increases in frequency of climate extremes may lower crop yields (Tubiello et al. 2007). Increased evapo-transpiration and increased soil moisture deficit due to increased temperature may have significant adverse impacts on agriculture production and food security. Water availability is a key component of food security as the availability of water supplies is the single most important factor in food production (McGuigan et al. 2002). Changes in glacier melt, along with other changes in high-altitude hydrology, will affect agricultural production (Malone 2010). The small landholdings, subsistence farmers and the poorest of the poor will face the biggest adverse impact of reduced agriculture production due to reduced water availability, which ultimately may lead to the famine.

5 Impacts on Extreme Events

The shrinkage and disappearance of mountain glaciers may result in changes in the flow characteristics of glacier fed rivers and changes in flood severity and frequency (Kaltenborn et al. 2010). Glaciers in Nepal Himalayas have been thinning and retreating at rates of 10–60 m per year and many small glaciers with surface area of less than 0.2 km^2 have already disappeared (Bajracharya et al. 2007). Upward shifts in the elevation of a terminus as great as 100 m have been recorded during the past 50 years and retreat rates of 30 m per year are common in Nepal Himalayas (Malone 2010). Increased melt of snow and glaciers in Nepal Himalayas has resulted in formation of glacial lakes and expansion of existing ones in the mountain valleys (Ives et al. 2010). Higher temperature may increase the likelihood of precipitation falling as rain rather than snow (IPCC 2007), which may result in increased likelihoods of floods during rainy season and decreased river flows during dry season. Chaulagain (2009) has revealed that decrease in snow cover areas has exponentially increased the ratio of maximum-to-minimum stream-flows (i.e. increased maximum flows and decreased minimum flows simultaneously) in Nepalese rivers. Moreover, increased melting of snow and ice including permafrost has induced an erodible state in the mountain soil which was previously non-erodible. This has increased likelihoods of landslides in the mountains. Because of warming, snowmelt begins earlier and winter becomes shorter, which affects river regimes, natural hazards, water supplies, infrastructures and people's livelihoods (Jianchu et al. 2007).

6 Socio-economic Consequences

Increase in evaporation, reduction in snow cover, and fluctuations in precipitation are key factors contributing to the degradation of mountain ecosystems. While too little water leads to vulnerability of production, too much water can also have adverse effects on crop productivity. Heavy precipitation events, excessive soil moisture and flooding disrupt food production and rural livelihoods (Bates et al. 2008). Changes in glacier regimes and runoff from snow and ice, combined with changes in precipitation timing and intensity may increase human vulnerability and may affect agriculture, forestry, health conditions and tourism (Kaltenborn et al. 2010). Decreased snow cover due to warming may result in direct adverse impacts on tourism. Rayamajhi (2012) has revealed that absence of snow on mountain caps may degrade the aesthetic view of the mountain and divert the tourists to other destinations. Increased risks of avalanches and glacier lake outburst floods in the mountain due to accelerated melting of snow and glaciers may adversely affect the tourist arrival in the mountains.

Water infrastructure, usage patterns and institutions have been developed in the context of current and past climatic conditions. Any substantial change in the frequency of floods and droughts, or in the quantity and quality or seasonal timing of water availability, will require adjustments that may be costly, not only in monetary terms but also in terms of societal and ecological impacts, including the need to manage potential conflicts between different interest groups. Increased risk of food and water shortage, water shortages for settlements, industry and societies; reduced hydropower generation potentials; potential for population migration due to floods and landslides are some of likely major adverse impacts associated with water resources.

Enhanced melting and increased length of the melt season of glaciers leads at first to increased river runoff and discharge peaks, while in the longer time-frame, glacier runoff is expected to decrease. The demand for water use is generally driven by changes in population, food consumption, economy, water pricing, technology, lifestyle and societal views regarding the value of freshwater ecosystems (Parry et al. 2007). The future socio-economic pathways will most likely increase the future water demand resulting in widening gap between water supply and demand, which will further exacerbate the existing water stress particularly during dry season. Currently, Nepal's annual renewable water availability is 7,656 m^3 per person, which is well above the global average water availability of 6,000 m^3 per capita per year and the water stress level of 1,700 m^3 per capita per year (FAO 2007). The analysis of different scenarios of future temperature increase and the United Nations population projection have revealed that the annual renewable water availability in Nepal even in 2100 AD will be above the critical line of water stress (see Fig. 5).

As the population continues to increase, more people will require more water for the cultivation of food, fibre and industrial as well as for livestock. Despite a significant surplus in annual water availability, many parts of Nepal, particularly urban and semi-urban areas are already facing seasonal water scarcity particularly during dry seasons. The seasonal water scarcity will most likely be more pronounced under the climate change. Availability of water at right time and right place is very much crucial for meeting the water demands. Imbalances between availability and demand, the degradation of water quality, inter-sectoral competition, and interregional and international conflicts, all bring water issues to the fore front (FAO 2007). The productivity of agricultural, forestry and fisheries systems depends critically on the temporal and spatial distribution of water (Bates et al. 2008).

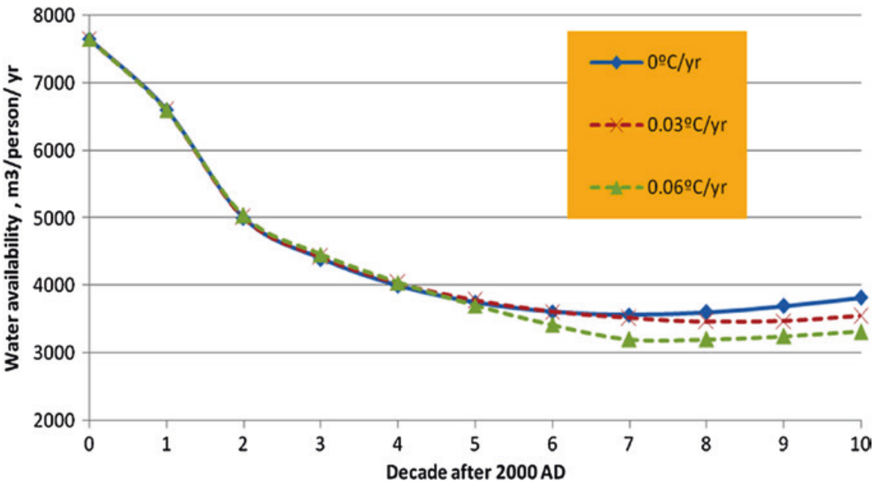

Fig. 5 Sensitivity of per capita water availability to temperature rise (2000–2100)

The impact of water scarcity is unevenly distributed among the sectors and income levels. Water scarcity is an issue of poverty. Unclean water and lack of sanitation are the major water issue for poor people. Water scarcity for poor people is not only about droughts or rivers running dry but it is also about guaranteeing the fair and safe access they need to sustain their lives and livelihoods (FAO 2007). Decreased runoff as a result of climate change will make it harder to improve safe access to drinking water, which leads to additional costs for the water supply sector and higher socio-economic impacts and follow-up costs. In the areas where extreme events become more intense and more frequent with climate change, the socio-economic costs of those events will increase significantly. Poor communities can be particularly vulnerable in such areas.

7 Conclusion

The melting of snow and glaciers and subsequent changes in water system have multi-facet impacts on society and economy because of direct linkage of water with people, ecosystem, economy and society. The impact of changed runoff regime and widening gaps between water supply and demand disproportionately falls more on poor, marginalized, subsistent farmers and the economic units which are directly dependent on natural system.

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