Expected Effects of Temperature Rise on Glacier Extent and Long-term Water Availability in Nepal Himalayas

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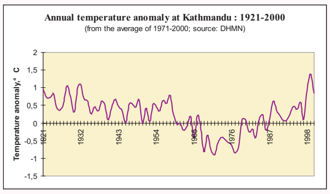
Abstract

About 43% of the total land areas of Nepal are located above 3000 m above mean sea level (amsl). Permanent snow line in the Nepal Himalayas lies near to 5000 m amsl and about 23% of the total land areas are located above it. Increasing temperatures are causing accelerated retreat of glaciers. Currently, about 3.6% of the total area of Nepal is occupied by glaciers and about 10% flows of Nepal's major rivers are contributed by glacier melts. A detailed mass balance analysis of 24 glaciers in Langtang valley in central Nepal based on the observed hydrological, meteorological and glaciological data reveal that the glaciers were melting by nearly 1100 mm annually in the 1990s. Applying the output of these analyses, all glaciers of Nepal were examined. The results show that about 73% of the present glacier area, about 87% of the present ice reserve and about 98.5% of present glaciers in Nepal Himalayas will disappear by 2100, if their current melting rate continues. This will cause a reduction in annual glacier-melt water in Nepal from 10.5 km³ in 2000 to 2.9 km³ in 2100. Disappearances of glaciers not only reduce the total water availability required for socio-economic activities of millions of people living downstream, but also result in more pronounced seasonal imbalances of flows and consequently more floods during summer (June-September) and more droughts during other seasons. This will cause water stresses in dry seasons despite too much of water in the summer-monsoon

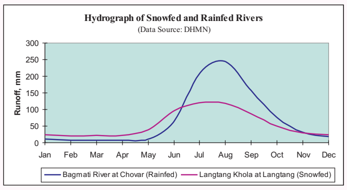
Background Information

Temperature Change



The oldest temperature records of Nepal at Kathmandu show that the trends almost follow the global temperature trends. The annual average temperatures were increasing by 0.05°C per year since 1971. The 1990s was the warmest decade in the record. The year 1999 was the warmest year.

Monthly Hydrograph of Snowfed and Rainfed Rivers of Nepal



The seasonal imbalance of flows i.e. too much of water in monsoon and too little of that in non-monsoon is less pronounced in the snowfed rivers in the Himalayas because the monsoon precipitation is stored in the form of ice or snow and melted down during non-monsoon season. The snow and glacier-melt water represents a substantial portion of dry season flows in the snowfed rivers of Nepal. The snow and glaciers in the high mountains are acting as "backups" for storing water for snowfed river systems and minimizing the seasonal imbalances of flows. In case of rainfed rivers, such a "backup" does not exist and the seasonal imbalances of flows are more pronounced.

Modeling of Glacier Mass Balance

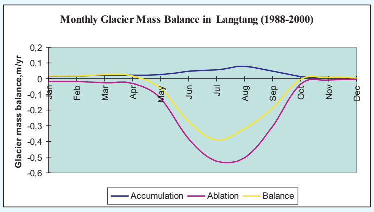
Empirical relation between mass balance and weather parameters

$$c = P \quad \text{if } T < -0.6$$
$$c = P(0.85-0.24T) \quad \text{if } -0.6 \le T \le 3.5$$
$$c = 0 \quad \text{if } T > 3.5$$
$$a = 0 \quad \text{if } T < -3.0$$
$$a = -0.30(T+3.0)^{1.2} \quad \text{if } -3.0 \le T \le 2.0$$
$$a = -30 \times 0.9T \quad \text{if } T > 2.0$$
$$b = c-a$$

Where,
c = Accumulation, cm/month; a = Ablation, cm/month;
b = Mass balance, cm/month; P = Average precipitation, cm/month
T = Average monthly temperature, °C

Source: Ageta and Kadota, 1992; Kadota et al., 1997; Naito et al., 2000; Naito et al., 2001; and Kadota and Ageta, 1992 with some modifications

Monthly Glacier Mass Balance at Langtang



Remarks
Though the accumulation of the glaciers is higher in summer than in winter, the ablation in this season exceeds significantly the accumulation resulting in substantial negative mass balance of the glaciers. Increasing temperatures will accelerate the melting of glaciers on one hand and decrease the amount of snowfall on the other. More precipitation will occur in the form of rain rather than snow with increasing temperatures.

Data and Methodology

Precipitation recorded at the Langtang (Kyangjing) meteorological station was considered as the representative precipitation for the whole study basin as there are no other existing stations nearby. The glacier information was obtained from UNEP/ICIMOD (2002) and topographical maps of the study area (HMGN, 1996). The effects of micro climates on the temperature were ignored. The temperature was assumed to be decreasing with altitude by an adiabatic lape rate of -0.6°C per 100 m of altitude.

Altogether 24 glaciers with total areas of 140.86 sqkm were analysed. The hydrological and meteorological records observed at the station of Langtang (Kyangjing) by the Department of Hydrology and Meteorology of Nepal for the period of 1988-2000 were used for the analysis.

Each glacier within the study basin was assumed to be uniformly distributed over its length. Glacier areas for each 100 m altitude level were calculated by interpolating the total area of particular glacier between its highest and lowest elevations. Then, the total areas were obtained by summing up those of all glaciers in that altitude.

The calculated glacier areas were multiplied by the empirical relation in order to calculate the total ablation, accumulation and mass balance for each month and for each 100 m altitude level. The specific glacier mass balance was obtained by dividing the total mass balance by the total area of the glaciers within the study basin.

Firstly, the mass balance calculation was made for the business as usual scenario (T=T0) with average of weather parameters of 1988-2000 observed at Langtang (Kyangjing). Then, further calculations were made with different temperature change scenarios from T=T+1°C to T=T+5°C. The calculated specific glacier mass balance values were applied to all 3252 glaciers in Nepal Himalayas in order to evaluate the contribution of glacier-melt water to the total water availability.

Model Outputs with Different Temperature Change Scenarios

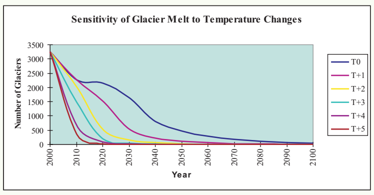
Output parameters	Unit	Temperature Change Scenarios, ^{0}C					
		T0	T+1	T+2	T+3	T+4	T+5
Ice reserve	10^9 m^3	19140	19140	19140	19140	19140	19140
Accumulation	10^6 m^3/year	118	104	89	75	62	49
Snow ablation	10^6 m^3/year	54	34	33	32	28	22
Glacier ablation	10^6 m^3/year	225	318	431	565	723	904
Total ablation	10^6 m^3/year	279	352	464	597	751	926
Annual balance	10^6 m^3/year	-161	-247	-374	-522	-689	-876
Sp.mass balance	m/year	-1,1	-1,8	-2,7	-3,7	-4,9	-6,2
Change in snowfall	%/year	0	-11	-24	-37	-48	-58

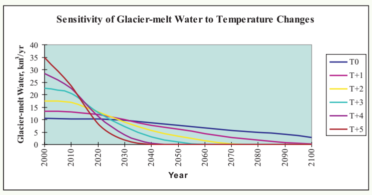
Sensitivity of Glacier Extent and Glacier-melt Water to Temperature Rise

Estimated Change in Glacier Extent and Glacier-melt Water in Nepal with BAU Scenario (T=T0)

Year	2000	2010	2020	2030	2040	2050	2060	2070	2080	2090	2100
Glacier area, km2	5322,5	5206,4	5177,2	4944,7	4445,4	3904,9	3336,3	2820,1	2487,4	2062,9	1451,9
Ice reserve, km3	480,6	423,3	366,1	310,1	257,8	211,7	171,6	137,3	107,8	82,4	61,9
Number	3252	2259	2151	1639	814	479	287	176	123	78	49
Glacier-melt water, km3	10,5	10,3	10,3	9,8	8,8	7,7	6,6	5,6	4,9	4,1	2,9

Remarks
The results show that about 73% of the present glacier area, about 87% of the present ice reserve and about 98.5% of the number of glaciers in Nepal Himalayas will disappear by 2100, if their current melting rate continues. This will cause a reduction in annual glacier-melt water in Nepal from 10.5 km³ in 2000 to 2.9 km³ in 2100.





Remarks
About 98.5% of current glaciers in Nepal Himalayas will disappear even without the further increase in average temperatures. If there will be further increase in temperature, which is very likely, the glaciers will disappear even faster. Actually, the life of any glaciers depends very much on the amount of increase in temperature. With 2°C rise in annual temperature, all glaciers will disappear by 2080. Similarly, no glaciers will be left by 2040; if there will be 5°C rise in annual temperature. The disappearances of glaciers will have direct impact on the water availability and flows in the Himalayan Rivers. Increasing temperatures will increase the glacier-melt water at the beginning, resulting in the possibilities of creation of glacier lakes at glacier terminus and the risks of glacier lake outburst floods. At the later stages, on the other hand, increasing temperature will result in the decreasing glacier-melt water because fewer glaciers will exist then. Decreasing glacier-melt water will impact directly on the dry season flows of the glacier-fed rivers because there is a substantial contribution of glacier-melt water to the dry season flows of these rivers now. This will create serious environmental and socio-economic impacts.

Conclusion

Increasing temperature will accelerate the melting of glaciers resulting in the decreasing water availability in the Nepal Himalayas. Rising temperature will increase the river flows due to the increased glacier-melt water at the beginning indicating the likelihoods of summer floods. Increased melting ultimately may cause the disappearance of the glacier that will most likely enhance peak floods in the summer monsoon and decrease low flows in the dry season. This will exacerbate the problem of too much of water in the summer-monsoon and to little of it in the dry seasons. If the current glacier-melting rate continues, there will be apparent seasonal water stresses in the near future (i.e. within the current century) despite enough surplus of annual water balance.