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# Global Climate Change and Melting of Himalayan Glaciers

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## Abstract:
Since industrialization, human activities have significantly altered the atmospheric composition, leading to climate change of an unprecedented character. The global mean temperature is expected to increase between 1.4 to 5.8ºC over the next hundred years. The consequences of this change in global climate are already being witnessed in the Himalayan glaciers and glacial lakes. The Himalayan glaciers are retreating at rates ranging from 10 to 60 metres per year and many small glaciers (<0.2 sq km) have already disappeared. Vertical shift of glaciers as great as 100m have been recorded during the last fifty years. With the result of retreating glaciers, the lakes are growing in number and size as well in the Himalaya. A remarkable example is Lake Imja Tsho in the Everest region; while this lake was virtually nonexistent in 1960, now it covers nearly 1 sq km in area. Similar observations were made in the Pho Chu basin of the Bhutan Himalaya, where the change in size of some glacial lakes has been as high as 800 per cent over the past 40 years. At present, several supraglacial ponds on the Thorthormi glacier are growing rapidly and consequently merging to form a larger lake. These lakes pose a threat of glacial lake outburst flood (GLOF), and GLOFs are often catastrophic on life and property of the mountain people living downstream. At least thirty-two GLOF events recorded in Himalaya that resulted in heavy loss of human lives and their property, destruction of infrastructure besides damages to agriculture land and forests. The global warming in the coming decades will amplify the GLOF events with the accelerating retreat of glaciers and formation of many potentially dangerous glacial lakes. Monitoring of glaciers and glacial lakes are utmost important to understand the status of the lake and need to prioritized for the installation of early warning systems and mitigation measures before planning the mountain infrastructure for the sustainable development. Regional cooperation is also required for knowledge management on GLOF issues due to trans-boundary nature of GLOF phenomena.

## Introduction
The Himalayan cryosphere, the water tower of the world, is the source of major river systems in Asia, the lifeline of more than 1.3 billion people living in the downstream valley. Climate change is causing the net shrinkage and retreat of glaciers and the increase in size and number of glacial lakes. Generally the glaciers and glacial lakes are spatially distributed in the high elevation as well as in the rugged terrain of remote areas. Most of these lakes had formed only on the second half of twentieth century due to global warming. The climate variability and global climatic change has brought significant impact on the high mountainous glacial environment. The glaciers are melting rapidly resulting initial increase in river runoff, which will reduce after certain time period below a critical threshold and formation, merging and expansion of glacial lakes to the stage of glacial lake outburst floods. Both of these phenomena will have the adverse impact on the livelihoods of the people living downstream. There are at least thirty-two recorded GLOF events in Nepal, Tibet Autonomous Region of China and Bhutan.

The impact of a GLOF event in downstream is quite extensive in terms of damage to roads, bridges, trekking trials, villages, and agricultural lands as well as the loss of human live and other infrastructure. The sociological impacts can be direct when human lives are lost or indirect when the agricultural lands are converted to debris filled lands and the village has to be shifted. The records of past GLOF events show that once in every three to ten years a GLOF has occurred in Himalaya with varying degrees of socio-economic impact. Therefore, proper monitoring of potential GLOF and early warning systems should be implemented to reduce the physical vulnerability in the watersheds of the Himalayan region.

**Global climate change and climate projection**

Since industrialization, human activities have resulted in steadily increasing concentrations of greenhouse gases in the atmosphere, leading to fears of enhanced greenhouse effect. The world's average surface temperature has increased between 0.3 and 0.6$^{o}$C over the past hundred years. The Intergovernmental Panel on Climate Change (IPCC), in its third assessment report, revealed that the rate and duration of the warming in the 20th century is larger than at any other time during the last one thousand years. The 1990s was likely to be the warmest decade of the millennium in the Northern Hemisphere, and the year 1998, the warmest year (IPCC, 2001a). According to the World Meteorological Organization (WMO), the mean global temperature in 2005 is deviated by +0.47°C from the average of the normal period 1961 -1990. It is thus one of the warmest years and currently ranks as the second warmest year worldwide (Faust, 2005), similarly year 2002 and 2003 will be the 3rd and 4th hottest years, respectively ever since climate statistics have been monitored and documented began in 1861.

According to the IPCC, 2001 and their assessments based on climate models, the increase in global temperature will continue to rise during the 21$^{st}$ century. The increase in the global mean temperatures by 2100 could amount anything from 1.4 to 5.8°C, depending on the climate model and greenhouse gases emission scenario. On the Indian sub-continent average temperatures are predicted to rise between 3.5 and 5.5°C by 2100 (Lal, 2002). An even higher increase is assumed for the Tibetan Plateau. There are several predicted future scenarios for the climate in the Himalayan region and it may be hazardous to speculate too much in which one that will come closest to the truth. However, it is quite clear that temperatures will increase, but difficult to estimate how much.

**Impact of climate change on glaciers**

These changes in climate will inevitably interact with changes in glaciers and glacial lakes. Results show that the recession rate has increased with rising temperature. A forecast was made that up to a quarter of the global mountain glacier mass could disappear by 2050 and up to half could be lost by 2100 (Kuhn, 1993a; Oerlemans, 1994; and IPCC, 1996b). For example, with the temperatures rise by 1°C, Alpine glaciers have shrunk by 40% in area and by more than 50% in volume since 1850 (IPCC, 2001b & CSE, 2002). Evidences have been conclusive enough to make glacier melting as an important indicator for climate change. The net shrinkage and retreat of glaciers causing the increase in size and number of glacial lakes and thereby the posssibility of increase in frequency of GLOFs in coming years. These changes in climate will have effects ultimately on life and property of mountain people.

*Glacier retreat in China*

Numerous studies were carried out during 1999-2001 lend credence to the link between climate change and glacier melting. All the glaciers (Valley) in the Himalaya have retreated by approximately a kilometer since the Little Ice Age [AD 1550-1850] (Mool P.K et al, 2001a). A long-term study entitled, 'The Chinese Glacier Inventory', by the Chinese Academy of Sciences has reported that during the last 24 years there has been a 5.5% shrinkage in volume of China's 46,928 glaciers, equivalent to the loss of more than 3000 sq km of ice. The study predicts that if climate continues to change at the present rate, two-thirds of China's Glaciers would disappear by 2050, and almost all would be gone by 2100 (*China Daily*, 23 September 2004). Evidence have been conclusive enough to make glacier melting and retreat an important indicator for climate change.

One of the study carried out by ICIMOD in 2004 (Mool et al, 2004) in the Poiqu basin of Tibet Autonomous Region of P R China revealed that the glaciers area has been decreased by 5.04% within 12 years during 1988 to 2000. The study also remarked that the Valley glaciers with IDs

5O191B0029 and 5O191C0009 on the eastern slope of the Xixiabangma mountain retreating 45m and 68m per year respectively with the expansion of associated glacial lakes (Figure 1).

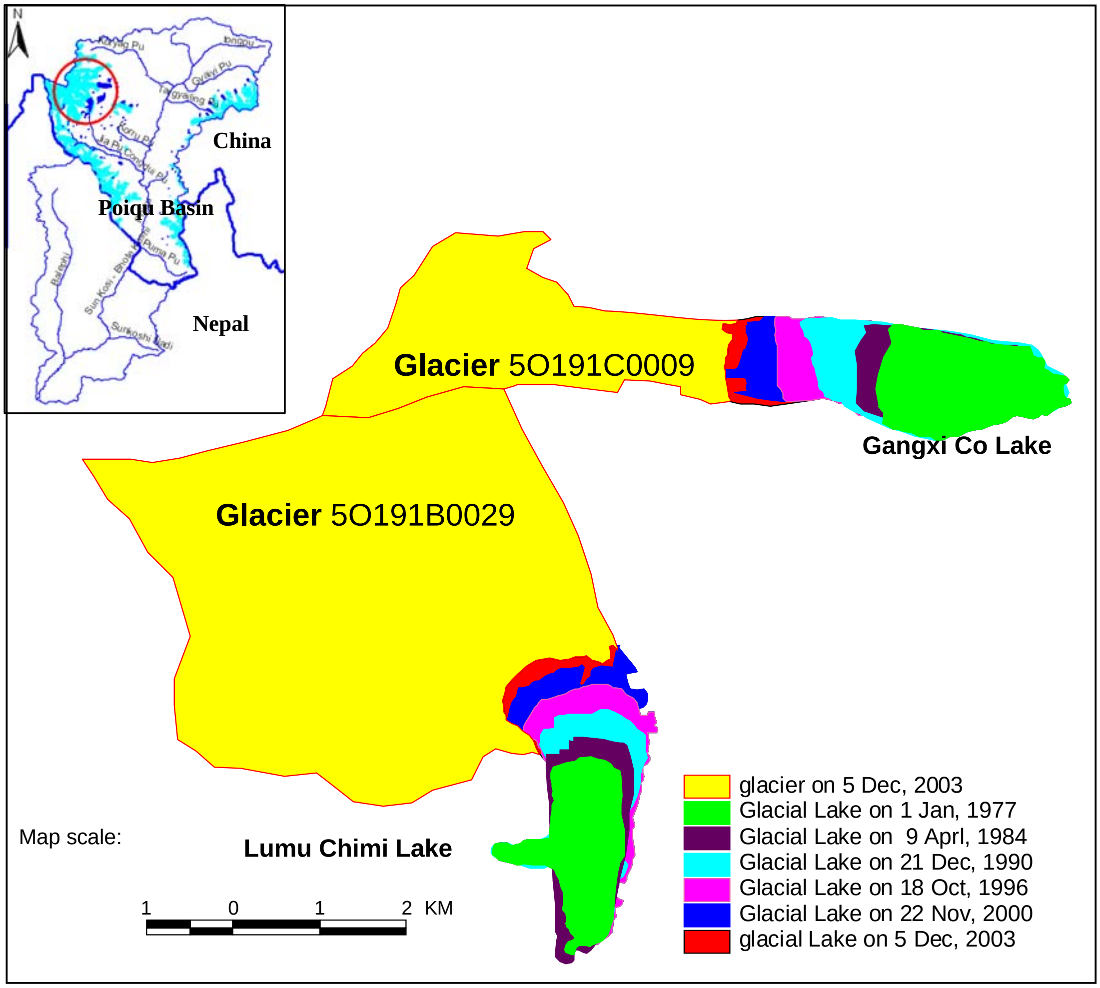



Figure 1: Glacier retreat and growth of Gangxi Co and Lumu Chimi Lakes in Poiqu basin, China

*Glacier retreat in India*

Earlier studies on selected glaciers of Indian Himalaya indicate that most of the glaciers are retreating discontinuously since post-glacial time. Of these, the Siachen and Pindari Glaciers retreated at a rate of 31.5m and 23.5m per year respectively (Vohra, 1981). Gangotri Glacier is retreating at an average rate of 18m per year Thakur et al. (1991). Shukla and Siddiqui (1999) monitored the Milam Glacier in the Kumaon Himalaya and estimated that the ice retreated at an average rate of 9.1m per year between 1901 and 1997. Dobhal et al. (1999) monitored the shifting of snout of Dokriani Bamak Glacier in the Garhwal Himalaya and found 586m retreat during the period 1962 to 1997. The average retreat was 16.5m per year. Matny found Dokriani Bamak Glacier retreated by 20m in 1998, compared to an average retreat of 16.5m over the previous thirtyfive years. (Matny, L., 2000).

Geological Survey of India (Vohra, 1981) studied the Gara, Gor Garang, Shaune Garang, Nagpo Tokpo Glaciers of Satluj River Basin and observed an average retreat of 4.22 - 6.8 m/year. The Bara Shigri, Chhota Shigri, Miyar, Hamtah, Nagpo Tokpo, Triloknath and Sonapani Glaciers in

Chenab River Basin retreated at the rate of 6.81 to 29.78 m/year. The highest and lowest retreat was in the Bara Shigri Glacier and Chhota Shigri Glacier respectively.

During the period 1963 -1997, Kulkarni and others found the retreat of Janapa Glacier by 696m, Jorya Garang by 425m, Naradu Garang by 550m, Bilare Bange by 90m, Karu Garang by 800 m and Baspa Bamak by 380m (Kulkarni et al 2004). They further observed a massive glacial retreat of 6.8 km (178 m/year) in Parbati Glacier in Kullu District during 1962 to 2000. In their studies they observed an overall 19 percent retreated in glaciated area and 23 percent in glacier volume in last 39 years.

Figure 2: Retreat of the Gangotri Glacier snout during the last 220 yrs. (Source: Jeff Kargel, USGS)

Based on the field survey carried out in 1999, the snout of Shaune Garang Glacier was marked at an elevation of 4460 masl in contrast to the Survey of India 1962 topographic map, which marked the snout at an altitude of 4360 masl (Philip and Sah 2004). This is indicating a vertical shift of 100m and horizontal shift of 1500m within a span of 37 years. These observations also suggest that global warming has affected snow-glacier melt and runoff pattern in the Himalaya. One of the best examples of glacier retreat is shown in the (Figure 2) where the position of Gangotri Glacier snout has been shifted about 2km upward from 1780 to 2001 and is in a continuous process.

*Glacier retreat in Bhutan*

Karma et al (2003) found the glacier retreat by 8.1% in 66 glaciers studied from the topographic map of 1963 and the satellite image of 1993. The glaciers area was 146.87 sq km in 1963 and decreased to 134.94 sq km in 1993 during these 30 years. The shrinkage of the smaller glaciers has the higher rate than the larger glacier. Some small glaciers of 0.1 to 0.2 sq km area glaciers are disappeared completely in 1993.

Ageta et al (2000) reported remarkable retreat of debris covered glacier in Lunana basin. Lugge Glacier retreated by 160m/yr from 1988 to 1993 with the high growth rate of Lugge Tsho Lake, Raphsthreng Glacier retreated 35m/yr in general from 1984 to 1998 but during 1988 to 1993 the retreat rate was 60m/yr. The Tarina Glacier retreat rate was 35m/yr from 1967 to 1988. The Lunana basin is the one where series of Glaciers and Glacial Lakes are in the cascading form (Figure 3). Due to retreat of glaciers the associated glacial lakes are growing in size shown by Gurung and Karma 2006 (Figure 4). One of the prominent observations in the decadal development of glacial lakes show the rapid growth of glacial lakes immediately after the formation till to certain level except in Drukchung Glacier.

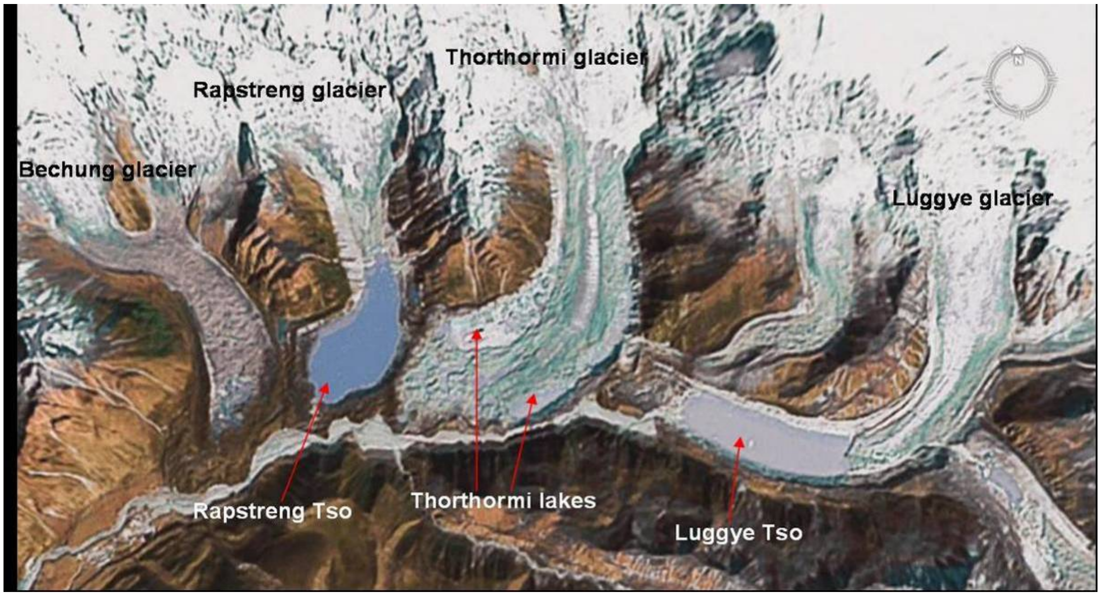



**Figure 3: Glaciers and Glacial Lakes in Lunana basin (Source: Google Earth, 2006)**

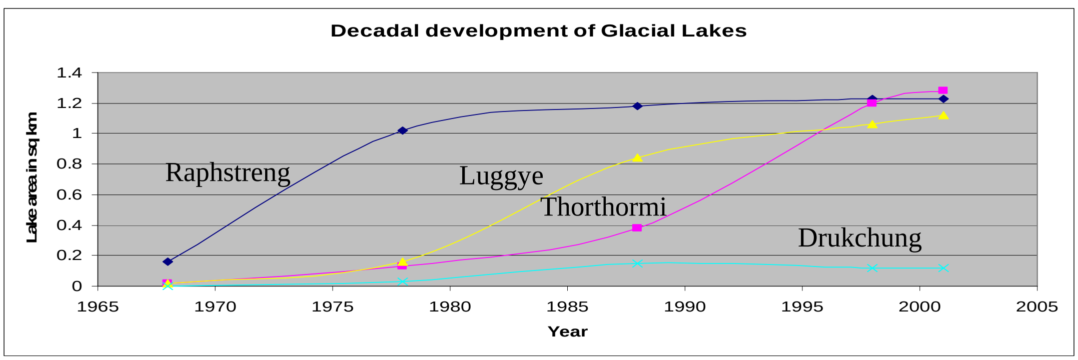
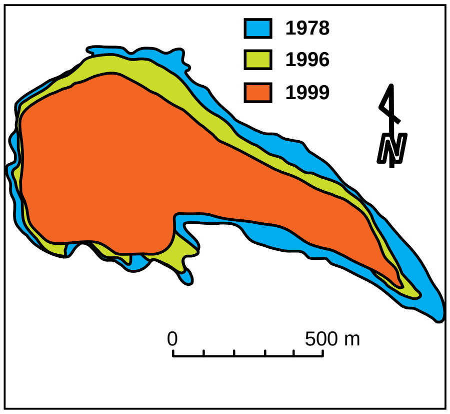


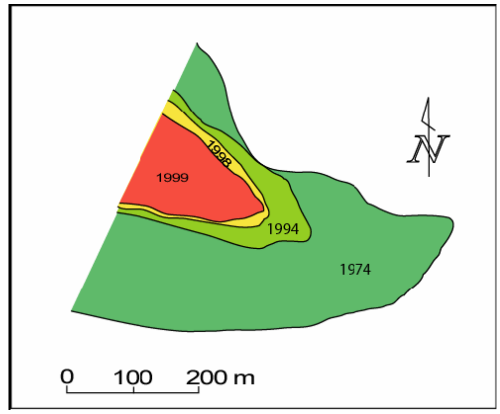

Figure 4: Development of Glacial Lakes in Lunana basin, Bhutan

*Glacier retreat in Nepal*

Since 1970s some glaciers from Kanchenjunga, Khumbu, Langtang, and Dhaulagiri region have been studied by different scholors to understand the glaciers activity and found the glacier retreat dramatically increased in the period between 1994 and 1998 (Figure 5). Asahi et al from Glaciological Expedition in Nepal (GEN, 2006) measured the glacier retreat in Khumbu and Shorang regions positioning the benchmarks in the vicinity of the termini on 19 small debris free glaciers. They found glacier retreat in Shorang region of around 8 m/year where as in the Khumbu region is 5 to 10 m/year and also remarked that the glacier retreat rate is accelerating since 1990.

Till now the overall glacier activity study in Nepal is unknown. Except in sporadic study of individual glaciers mainly the valley glaciers, the first attempt of study of glaciers and glacial lakes throughout the country was carried out by ICIMOD in 2001, which provide the baseline information of glaciers and glacial lakes.




*a. AX010 Glacier, Shorang Himal, Nepal* *b. Rika Samba Glacier, Dhaulagiri region, Nepal*

Figure 5: Maps showing the changes in the glacier area in different date (Source: Fujita, 2001)

The supraglacial lakes mostly formed at the tongue of the glacier moraine. In some the moraine consist dead ice core. Most of the large glacial lakes had grown from the small supraglacial lake. Due to melt of ice core the supraglacial lakes expanded and formed as moraine dammed lake. Some of the lakes studied in detail since from the beginning of the lake formation show the rate of lake extension is propertional to glacier retreat. For example the Imja Tsho glacial lake and Tsho Rolpa glacial lakes are expanding about 41m and 66m per year respectively which is the rate of glacier retreat of respective glaciers. Clear expansion of Imja Lake can be seen on different satellite images from 1962 to 2006 (Figure 6).

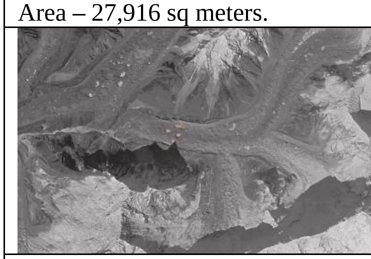
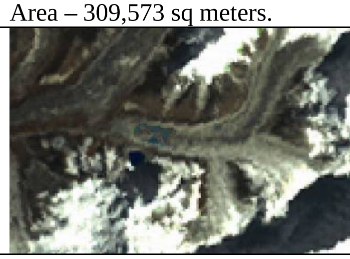
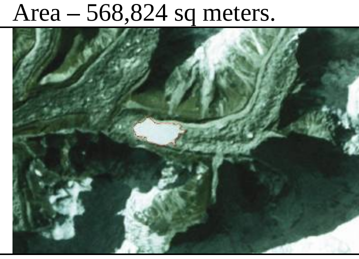
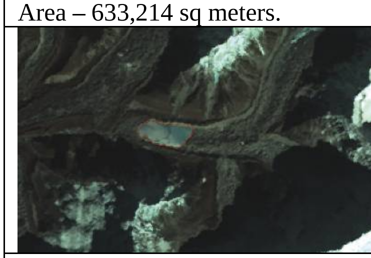
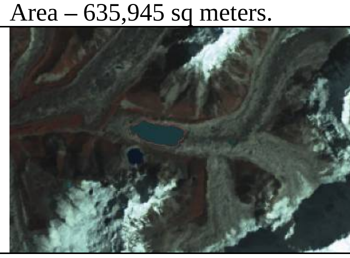
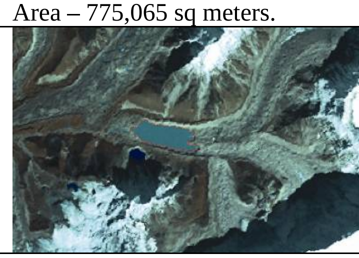
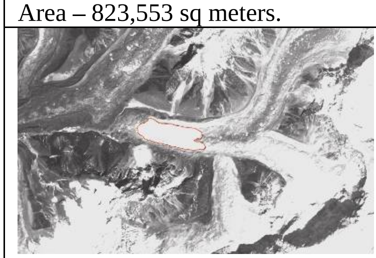
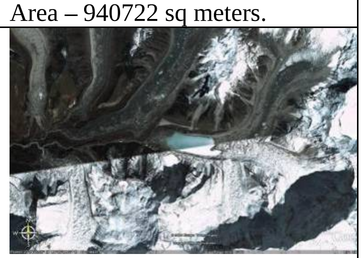
Between 1970 and 2000 during this 30 years period the loss of glacier area was by 5.88% or 0.2% per year in the Tamor River basin of Nepal (Bajracharya et al. 2006). Out of the 2323 inventoried lakes 330 lakes are having the area larger than 0.02 square kilometer and associated with the glaciers. Among them 65 lakes including 15 new lakes are growing in size due to glacier retreat (Bajracharya et al. 2005).

**GLOF in Himalaya**

ICIMOD with its partner institutes mapped about 15,000 glaciers, 9000 lakes and 200 potentially dangerous glacial lakes including 21 GLOF events in the Himalayan region except Arunanchal and Azad Jammu & Kashmir (AJK) region. The database of glaciers, glacial lakes, and glacial lake outburst flood in HKH region serves as the baseline data and information for climate change study, planning for water resource development, to understand and mitigate GLOF associated hazards, thus linking science to policy. However with the view of catastrophic events of GLOF in the past monitoring, mitigation and awareness of potential GLOF in the region is necessary to reduce the GLOF hazard.

Most of the glacial lakes in the Himalayan region are known to have formed within the last 5 decades, and a number of Glacial Lake Outburst Flood (GLOF) events have been reported in this region (Table 1). At least between 3 to 10 years one GLOF event was recorded in Himalayan region. These GLOF events have resulted in loss of many lives, as well as the destruction of houses, bridges, fields, forests and roads. The hazardous lakes, however, are situated in remote areas. If the potential GLOF could be known in advance, the GLOF hazard could be reduced by saving life and properties of local communities.

Past GLOF events have shown  transboundary damaging effects downstream which are shown in the Table 1. The GLOF occured in Tibet/China and damage occurred in Tibet as well as in Nepal (Figure 8). GLOFs exacerbate land degradation, increase variations in the hydrological regime, degrade biodiversity, and trigger many socioeconomic externalities. Climate change will thus intensify and accelerate these impacts and further burden the human and natural systems over a wide area, far beyond the mountain ecosystem.

| | | |
|---|---|---|
| 15 Dec 1962 (Corona)<br>Area – 27,916 sq meters. | 15 Oct 1975 (Landsat MSS)<br>Area – 309,573 sq meters. | 02 Dec 1983 (Space Shuttle)<br>Area – 568,824 sq meters. |
|  |  |  |
| 11 Dec 1989 (Landsat5 TM)<br>Area – 633,214 sq meters. | 22 Sept 1992 (Landsat5 TM)<br>Area – 635,945 sq meters. | 30 Oct 2000 (Landsat7 ETM+)<br>Area – 775,065 sq meters. |
|  |  |  |
| 19 March 2001 (LISS 3)<br>Area – 823,553 sq meters. | Jan 2006 Google Earth<br>Area – 940722 sq meters. | Birds eye view of Lake Imja Tsho<br>(Photo: Oct 2007) |
|  |  |  |
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| Figure 6: View and aerial extension of Imja Glacial Lake from 1962 to 2006 in different satellite images and field observation in Oct 2007. | | |

**Inventory of glaciers and glacial lakes in the Himalaya**

The International Centre for Integrated Mountain Development (ICIMOD) and its partner Institutes, in collaboration with United Nations Environment Programme /Regional Resource Centre for Asia and the Pacific (UNEP/RRC-AP) carried out a systematic inventory of glaciers and glacial lakes of Nepal and Bhutan in 1999–2001. Later, the study was continued in collaboration with the Asia-Pacific Network for Global Change Research (APN) and the global change SysTem for Analysis, Research and Training (START), and expanded to all the ten sub-basins of the Indus River in Pakistan, all sub-basins of the Ganges River in the Tibet Autonomous Region of the Peoples' Republic of China, and Tista River Basin along with Himachal Pradesh Himalaya and Uttaranchal Himalaya of India (Table 2 and Figure 7). Once the study on Arunanchal Pradesh and Ajad Jammu & Kashmir Himalayas and northern Afghanistan area are completed, the entire database of glaciers and glacial lakes of the Hindu Kush–Himalaya will serve at the scale of 1:50,000.

The main objective of the study is to link priority topics in the research framework by identifying the formation of dangerous glacial lakes in the region as a result of global climate change, with direct impacts on terrestrial change and human vulnerability and adaptation.

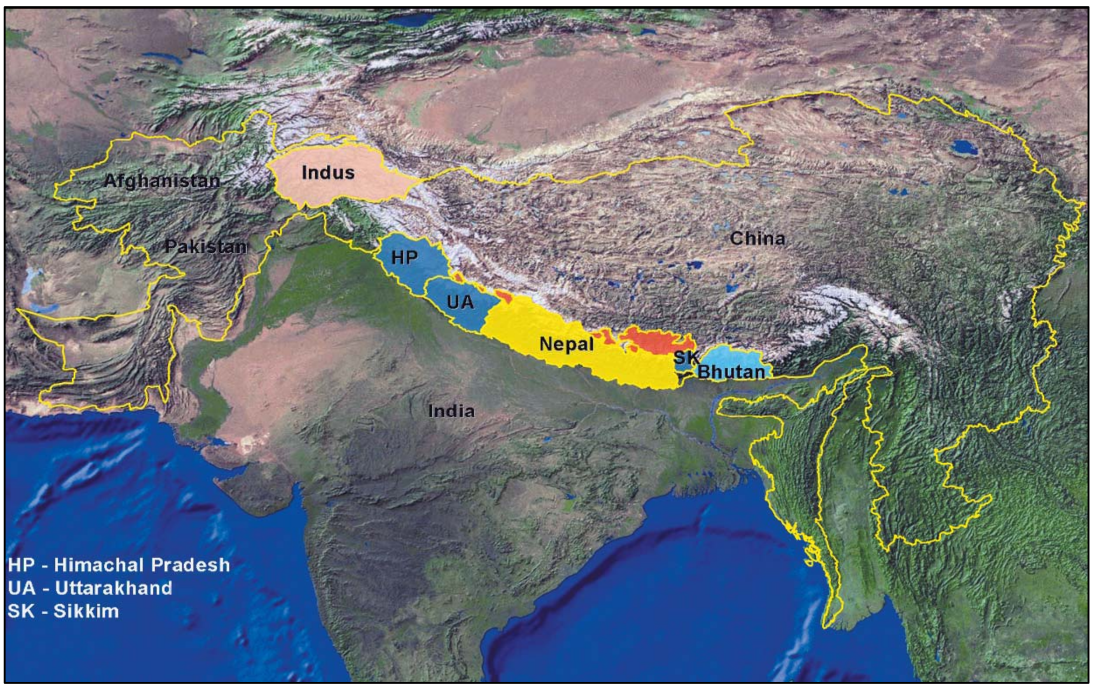


Figure 7: Hindu Kush-Himalayan region showing the areas covered by the Inventory of Glaciers and Glacial Lakes Studied by ICIMOD

**Conclusions**

The northern hemisphere experienced many warm years after 1990 since climate statistics have been monitored and documentation began in 1861 and also expected increase in the global mean temperatures in coming years. The amount could be anything from 1.4 to 5.8°C in 2100 depending on the climate model and greenhouse gases emission scenario. Evidences have been conclusive enough to make glacier melting and an important indicator of climate change. During the last 30 years there has been a 5.5 % shrinkage in volume of glaciers in China and similar results are also shown in Nepal, India and Bhutan. The valley glaciers and small glaciers are retreating faster with the formation and expansion of glacial lakes. Most of the glacial lakes, which are known to have formed within the last 5 decades. Subsequently GLOF events are recorded in the region at least one between 3 to 10 years. These GLOF events have trans-boundary effect resulting loss of many lives, as well as the destruction of houses, bridges, fields, forests, hydro-powers, roads, etc. Regular monitoring of glaciers and glacial lakes and adaptation measures including early warning systems and mitigation measure are required in potential GLOF area. Important to link this scientific knowledge of potential GLOF hazards to policy, planning and community to reduce the GLOF risk.

**References**


Ageta, Y., Iwata, S., Yabuki H., Naito, N., Sakai, A., Narama, C. and Karma, (2000) 'Expansion of glacier lakes in recent decades in the Bhutan Himalayas'. *In Debris-covered glaciers.* IAHS, publ. no. 264, 165 – 175p.

Asahi K., Kadota T., Naito N., and Ageta Y., (2006) 'Variations of small glaciers since the 1970s to 2004 in Khumbu and Shorang regions, eastern Nepal'. *In Data Report 4* (2001-2004). *Glaciological Expedition in Nepal (GEN) and Cryosphere Research in the Himalaya (CREH)*. Graduate School of Eviromnmentl Studied, Nagoya University and Department of Hydrology and Meteorology, HMG of Nepal. 109 – 136p.

Bajracharya, S. R.; Mool, P. K.; Shrestha, B. R., (2007) *Impact of Climate Change on Himalayan Glaciers and Glacial Lakes: Case Studies on GLOF and Associated Hazards in Nepal and Bhutan.* Kathmandu, ICIMOD, 136p.

Bajracharya S. R., and Mool P. K., (2006) *Impact of global climate change from 1970s to 2000s on the glaciers and glacial lakes in Tamor Basin, eastern Nepa*l, ICIMOD.

Bajracharya S. R., and Mool P. K., (2005) 'Growth of hazardous glacial lakes in Nepal' *In Proceedings of the JICA Regional seminar on natural disaster mitigation and issues on technology transfer in south and southeast Asia.* Sep 30 to 13 October 2004, Kathmandu, Tri-Chandra Campus, Tribhuvan University, 131-148p.

Center for Science and Environment, (2002) 'Melting into Oblivion' *In Down To Earth*, 15 May 2002.

*China Daily*, 23 September 2004

Dobhal, D.P, Gergan, J.T., Thayyen, R.J. (1999) 'Recession of Dokriani Glacier, Garhwal Himalaya' - An overview. Symp. On snow, ice and glaciers. In *A Himalayan Perspective*. Geol. Survey India, Abst. Vol. 30-33p.

Eberhard F., (2005) 'Climate Review' Munich Re, Topics Geo, *In Annual Review: Natural catastrophes 2005*. Knowledge Series, 51p.

Fujita, K., Kadota, T., Rana, B., Shrestha, R. B., and Ageta, Y., (2001) 'Shrinkage of Glacier AX010 in Shorong region, Nepal Himalayas in the 1990s'. *In Glaciological Research* 18, pp 51-54.

IPCC, (1996b) 'Climate Change 1995 'Impacts, Adaptation and Mitigtion of Climate Change: Scientific and Technical Analyses'. Contribution of Working Group II to the Second Assessment Report of the *Intergovernmental panel on Climate Change*.

IPCC (2001a) *IPCC Third Assessment Report- Climate Change 2001*. Working Group I: Technical Summary. Geneva, WMO and UNEP.

IPCC (2001b) *IPCC Third Assessment Report- Climate Change 2001*. Working Group II: Impacts, Adaptation and Vulnerability. Summary for Policy Makers. Geneva, WMO and UNEP.

Ives, J.D (1986) *Glacial Lake Outburst Floods and Risk Engineering in the Himalaya*, ICIMOD Occasional Paper No.5, ICIMOD.

Karma, Ageta, Y., Naito, N., Iwata, S., and Yabuki, H., (2003) 'Glacier distribution in the Himalayas and glacier shrinkage from 1963 to 1993 in the Bhutan Himalayas'. *In Bull.* Glaciological Research 20 @Japanese Society of Snow and Ice, 29–40p.

Kuhn, M., (1993a) 'Possible future contribution to sea level chane from samall glaciers'. *In: Climate and Sea Level Change*: Obsevations, Projections and Implications (Eds.R.A. Warrick et al.) Cambridge University press, Cambridge, UK. 134-143.

Kulkarni, A.V., Rathore B. P., Suja A., (2004) 'Monitoring of glacial mass balance in the Baspa basin using Accumulation Area Ratio method' *In Current science* 86(1), 101-106.

Lal M., (2002) 'Possible impacts of global climate change on water availability in India'.*In Report to Global Environment and Energy in the 21st Century*. New Delhi: Indian Institute of Technology.

Matny, L. (2000) 'Melting of Erth's Ice Cover Reaches New High'.*In Worldwatch News* Brief, 06 March 2000.

Mool P.K (1993) *Glacier Lake Outburst Floods in Nepal, WECS* Bulletin June 1993

Mool, P.K., Bajracharya, S.R., and Joshi, S. P., (2001a) *Inventory of Glaciers, Glacial Lakes and Glacial Lake Outburst Floods, Monitoring and Early Warning Systems in the Hindu Kush-Himalayan Region: Nepal*, ICIMOD & UNEP RRC-AP.

Mool, P.K., Wangda, D., Bajracharya, S.R., Joshi, S. P., Kunzang, K., and Gurung, D.R., (2001b) *Inventory of Glaciers, Glacial Lakes and Glacial Lake Outburst Floods, Monitoring and Early Warning Systems in the Hindu Kush-Himalayan Region: Bhutan*, ICIMOD & UNEP RRC-AP.

Mool P. K., Tao C., and Bajracharya S. R, (2004) *Monitoring of glaciers and glacial lakes from 1970s to 2000 in Poiqu basin, Tibet Autonomous Region PR China*. ICIMOD.

Mool, P.K.; Bajracharya, S.R.; Shrestha, B.R. (2005a) 'Inventory of Glaciers and Glacial Lakes and the Identification of Potential Glacial Lake Outburst Floods (GLOFs) Affected by Global Warming in the Mountains of India, Pakistan and China/Tibet Autonomous Region (APN 2004-03-CMY–Campbell)'. In *APN Newsletter*, 11(4): 6-7.

Mool, P.K.; Bajracharya, S.R.; Shrestha, B.R. (2005b) 'Glaciers, Glacial Lakes and Glacial Lake Outburst Floods in the Hindu Kush-Himalaya'. In *Proceedings of the International Karakorum Conference*, 25-27 April 2005, Islamabad, Pakistan, Abstract Volume.

Oerlemans, J., (1994) *Quantifying global warming from the retreat of glaciers.* Science 264, pp 243 – 245.

Philip, G., Sah, M.P., (2004) 'Mapping Repeated Surges and Retread of Glaciers Using IRS-1C/1D Data: A Case Study of Shaune Garang Glacier, Northwestern Himalaya'. In International Journal of *Applied Earth Observation and Geoinformation* Vol. 6(2), 127-141p.

Shukla, S.P, Siddiqui, M.A., (1999) 'Recession of the snout front of Milam Glacier, Goriganga valley, District Pithoragah, Uttar Pradesh. In Symp. on snow, ice and glaciers'. *A Himalayan Perspective*. Geol. Surv. India, (In: Abst. Vol.), 27-29p.

Shrestha, A.B.; Wake, C.P.; Mayewski, P.A.; Dibb, J.E., (1999) 'Maximum Temperature Trends in the Himalaya and its Vicinity: An Analysis Based on Temperature Records from Nepal for the Period 1971 – 94. In *Journal of Climate*, 12: 2775 – 2767.

Thakur, V.C., Virdi, N.S., Gergan, J.T., Mazari, R.K., Chaujar, R.K., Bartarya, S.K., Philip, G., (1991) *Report on Gaumukh. The snout of the Gangotri glacier* (Unpublished Report submitted to DST, New Delhi).

Vohra, C.P., (1981) *Note on recent glaciological expedition in Himachal Pradesh*. Geol. Survey of India. Sp. Vol., 6, 26-29p.

Zhu P., Li T., (2001) 'Flash Flooding Caused by Landslide Dam Failure'. *In ICIMOD Newsletter* No. 38, Winter 2000/2001, pp. 4-5.

| Table 1: GLOF events that have occurred in China (Tibet), Nepal and Bhutan | | | | | | |
|---|---|---|---|---|---|---|
| No. | Index | Date | River basin | Lake | Latitude | Longitude |
| Tibet (China) | | | | | | |
| 1 | 4 | Aug 1935 | Sun Koshi | Tara-Cho | 28° 17’ 00” | 86° 08' 00” |
| 2 | 2 | 21 Sept 1964 | Arun | Gelhaipco | 27° 58' 00” | 87° 49' 00” |
| 3 | 5 | 1964 | Sun Koshi | Zhangzangbo | 28° 04' 01” | 86° 03' 45” |
| 4 | 6 | 25 Aug 1964 | Trisuli | Longda | 28° 37’ 01” | 85° 20’ 58” |
| 5 | 3 | 1968 | Arun | Ayaco | 28° 21’ 00” | 86° 29' 00” |
| 6 | 3 | 1969 | Arun | Ayaco | 28° 21’ 00” | 86° 29' 00” |
| 7 | 3 | 1970 | Arun | Ayaco | 28° 21' 00” | 86° 29' 00” |
| 8 | 5 | 11 Jul 1981 | Sun Koshi | Zhangzangbo | 28° 04' 01” | 86° 03' 45” |
| 9 | 1 | 27 Aug 1982 | Arun | Jinco | 28° 00' 35” | 87° 09' 39” |
| 10 | | 6 Jun 1995 | Trisuli | Zanaco | 28° 39’ 44” | 85° 22’19” |
| China | | | | | | |
| 11 | | 10 Jun 1940 | Kangboqu-Ahmchu | Qubixiama-Cho | North of Sikkim | |
| 12 | | 16 Jul 1954 | Nyangqu | Sangwang-Cho | North of Bhutan | |
| 13 | | 26 Sep 1964 | Tangbulang | Damenhai-Cho | | |
| 14 | | 23 Jul 1972 | Xibaxiaqu | Poge-Cho | | |
| 15 | | 24 Jun 1981 | Yarlung Zangbo | Zari-Cho | | |
| 16 | | 14 Jul 1988 | Palong Zangbo | Mitui-Cho | | |
| Nepal | | | | | | |
| 17 | L | 450 years ago | Seti Khola | Machhapuchhre | 28° 31' 13" | 83° 59' 30" |
| 18 | D | 3 Sept 1977 | Dudh Koshi | Nare | 27° 49' 47" | 86° 50' 12" |
| 19 | A | 23 Jun 1980 | Tamor | Nagma Pokhari | 27° 51' 57" | 87° 51' 46" |
| 20 | E | 4 Aug 1985 | Dudh Koshi | Dig Tsho | 27° 02' 36" | 86° 35' 02" |
| 21 | H | 12 Jul 1991 | Tama Koshi | Chhubung | 27° 52' 37" | 86° 27' 38" |
| 22 | G | 3 Sept 1998 | Dudh Koshi | TamPokhari | 27° 44’ 20” | 86° 50’ 45” |
| 23 | B | Unknown | Arun | Barun Khola | 27° 50' 33" | 27° 50' 33" |
| 24 | C | Unknown | Arun | Barun Khola | 27° 49' 46" | 87° 05' 42" |
| 25 | F | Unknown | Dudh Koshi | Chokarma Cho | 27° 54’21” | 86° 54’48” |
| 26 | I | Unknown | Kali Gandaki | Unnamed | 29° 13' 14" | 83° 42' 09" |
| 27 | J | Unknown | Kali Gandaki | Unnamed | 29° 07’03" | 83° 44' 19" |
| 28 | K | Unknown | Mugu Karnali | Unnamed | 29° 39’00” | 82° 48’00” |
| Bhutan | | | | | | |
| 29 | | 1957 | Pho Chu | Tarina Tso | 28° 06’ 06” | 89° 54’ 11” |
| 30 | | 1960 | Pho Chu | Unnamed | Eastern Lunana | |
| 31 | | 1960? | Chamkhar Chu | BachamanchaTso | 28° 01’ 55” | 90° 40’ 41” |
| 32 | | 7 Oct 1994 | Pho Chu | Luggye Tso | 28° 05’ 00” | 90° 18’ 28” |

Table 2: Summary of glaciers, glacial lakes and potentially dangerous glacial lakes studied in Bhutan, Nepal, India, Pakistan, and China during 1999-2004 by ICIMOD.

| S.N | River Basins | Glaciers | | | Glacial Lakes | | |
|---|---|---|---|---|---|---|---|
| | | **Number** | **Area ($km^2$)** | **Ice Reserve ($km^3$)** | **Number** | **Area ($km^2$)** | **Potential danger** |
| **Pakistan (Indus River)** | | | | | | | |
| 1 | Swat | 233 | 224 | 12.22 | 255 | 15.86 | 2 |
| 2 | Chitral | 542 | 1904 | 258.82 | 187 | 9.36 | 1 |
| 3 | Gilgit | 585 | 968 | 83.34 | 614 | 39.17 | 8 |
| 4 | Hunza | 1050 | 4677 | 808.79 | 110 | 3.21 | 1 |
| 5 | Shigar | 194 | 2240 | 581.27 | 54 | 1.09 | 0 |
| 6 | Shyok | 372 | 3548 | 891.80 | 66 | 2.68 | 6 |
| 7 | Indus | 1098 | 688 | 46.38 | 574 | 26.06 | 15 |
| 8 | Shingo | 172 | 37 | 1.01 | 238 | 11.59 | 5 |
| 9 | Astor | 588 | 607 | 47.93 | 126 | 5.52 | 9 |
| 10 | Jhelum | 384 | 148 | 6.94 | 196 | 11.78 | 5 |
| | **Total** | **5218** | **15041** | **2738.50** | **2420** | **126.35** | **52** |
| **India** | | | | | | | |
| | **Tista River** | **285** | **576.51** | **64.78** | **266** | **20.20** | **14** |
| | **Himachal** | | | | | | |
| 1 | Beas | 358 | 758 | 76.40 | 59 | 236.20 | 5 |
| 2 | Ravi | 198 | 235 | 16.88 | 17 | 9.16 | 1 |
| 3 | Chenab | 681 | 1705 | 187.66 | 33 | 3.22 | 5 |
| 4 | Satluj | 945 | 1218 | 94.45 | 40 | 136.46 | 3 |
| 5 | Sub-basins | 372 | 245 | 11.96 | 7 | 0.18 | 2 |
| | **Total** | **2554** | **4161** | **387.35** | **156** | **385.22** | **16** |
| | **Uttaranchal** | | | | | | |
| 1 | Yamuna | 124 | 173 | 17.88 | 20 | 0.17 | 0 |
| 2 | Bhagirathi | 393 | 1034 | 143.41 | 32 | 0.44 | 0 |
| 3 | Alaknanda | 540 | 1675 | 191.36 | 54 | 1.37 | 0 |
| 4 | Kali | 382 | 1178 | 122.78 | 21 | 0.51 | 0 |
| | **Total** | **1439** | **4060** | **475.43** | **127** | **2.49** | **0** |
| **Ganges basin in TAR China** | | | | | | | |
| 1 | Pumqu | 900 | 1331 | 130.95 | 383 | 52.01 | 38 |
| 2 | Poiqu | 151 | 232 | 19.02 | 91 | 15.66 | 9 |
| 3 | Rongxer | 206 | 224 | 30.44 | 183 | 8.40 | 16 |
| 4 | Jilongcangbu | 180 | 419 | - | 72 | 3.32 | 2 |
| 5 | Zangbuqin | 64 | 86 | - | 5 | 0.18 | 0 |
| 6 | Daoliqu | 43 | 61 | - | 7 | 0.38 | 0 |
| 7 | Jiazhagangge | 96 | 143 | - | 14 | 0.52 | 1 |
| 8 | Majiacangbu | 147 | 216 | - | 69 | 4.73 | 11 |
| | **Total** | **1578** | **2862** | | **824** | **85.19** | **77** |
| **Nepal** | | | | | | | |
| 1 | Koshi River | 779 | 1410 | 152.06 | 1062 | 25.09 | 16 |
| 2 | Gandaki River | 1025 | 2030 | 191.39 | 338 | 12.50 | 4 |
| 3 | Karnali River | 1361 | 1740 | 127.81 | 907 | 37.67 | 0 |
| 4 | Mahakali River | 87 | 143 | 10.06 | 16 | 0.38 | 0 |
| | **Total** | **3252** | **5323** | **481.23** | **2323** | **75.70** | **20** |
| **Bhutan** | | | | | | | |
| 1 | Amo Chu | 0 | 0 | 0 | 71 | 1.83 | 0 |
| 2 | Wang Chu | 36 | 49 | 3.55 | 221 | 6.47 | 0 |
| 3 | Puna Tsang Chu | 272 | 503 | 43.27 | 980 | 35.08 | 13 |
| 4 | Manas Chu | 310 | 377 | 28.77 | 1383 | 55.51 | 11 |
| 5 | Nyere Ama Chu | 0 | 0 | 0 | 9 | 0.07 | 0 |
| 6 | Northern basins | 59 | 388 | 51.72 | 10 | 7.81 | 0 |
| | **Total** | **677** | **1317** | **127.25** | **2674** | **106.87** | **24** |
| **Himalaya** | | **15003** | **33339** | **4272** | **8790** | **799.49** | **203+1** |