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The impact of global warming on the glaciers of the Himalaya

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ABSTRACT

Since industrialization and human activities is advancing the concentration of greenhouse gases in the atmosphere is steadily increasing. As a result of green house gas effect the world's average surface temperature has increased between 0.3 and 0.6°C over the past hundred years. There is expectation of global average temperature increase by 1.4 to 5.8°C in 2100 with the increase of carbondioxide. The increase in average temperature will have the direct impact on glaciers and glacial lakes in Hindu Kush-Himalayan (HKH) region. The glaciers of the HKH region are retreating and as a result the glacial lakes associated with the glaciers are increasing in number and size to the level of potential glacial lake outburst flood. Many GLOFs are recorded in region at least one in 3 to 10 years since 1970s. The GLOF events have trans-boundary effect resulting loss of many lives and property along the downstream.

The International Centre for Integrated Mountain Development (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

1 INTRODUCTION

The glaciers of the Himalayan region are nature's renewable storehouse of fresh water that benefits hundreds of millions of people downstream, if properly used. However, glaciers in the region are retreating in the face of accelerated global warming, and the resultant long-term loss of natural fresh water storage. More immediately, as glaciers retreat lakes form behind newly exposed terminal moraine. Rapid accumulation of water in these lakes can lead to sudden breaching of the unstable 'dams' behind which they are formed. The resultant discharges of huge amounts of water and debris -known as a Glacial Lake Outburst Floods, or GLOFs -often have catastrophic effects. There are at least twenty-one 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 Nepal with varying degrees of socio-economic impact. From the scenario of time series satellite images the glaciers are retreating and consequently number as well as size of the glacial lakes is growing to the stage of potential GLOF. 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 if possible most appropriate mitigation measures should be taken.

2 GLOBAL CLIMATE CHANGE AND FUTURE CLIMATE PREDICTIONS

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°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 21st 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.

3 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). Climate change is causing the net shrinkage and retreat of glaciers and the increase in size and number of glacial lakes and thereby the frequency of GLOFs in recent years. These changes in climate will have effects ultimately on life and property of mountain people.

3.1 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 (Figure 1). Similarly five Valley Glaciers on the northern slope of the Laptshegang Mountain had also shown the glacier shrunk with the average rate of 27,800m^2 area and 20m length per year.

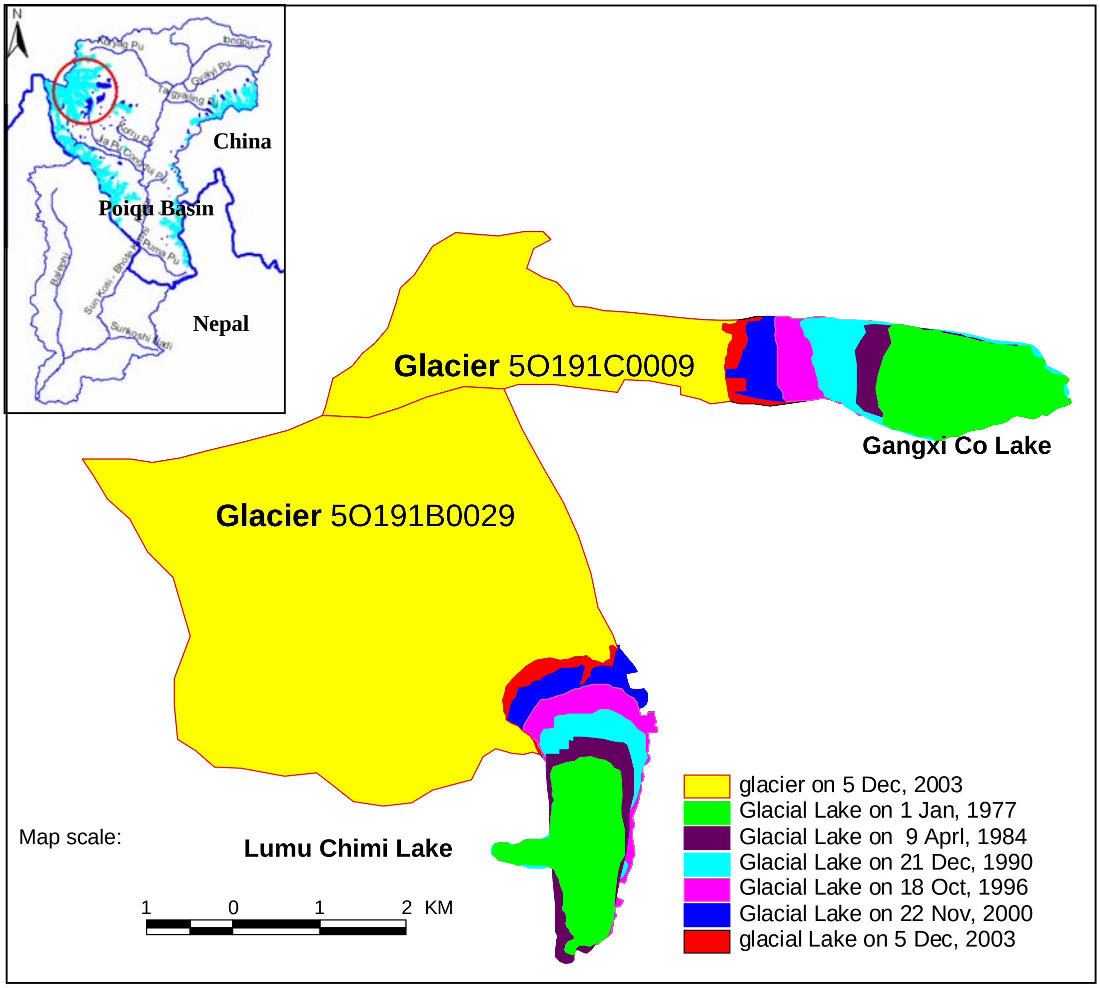


Figure 1: Glacier retreat and growth of Gangxi Co and Lumu Chimi Lakes in Poiqu basin, China

3.2 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.

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.

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

3.3 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.

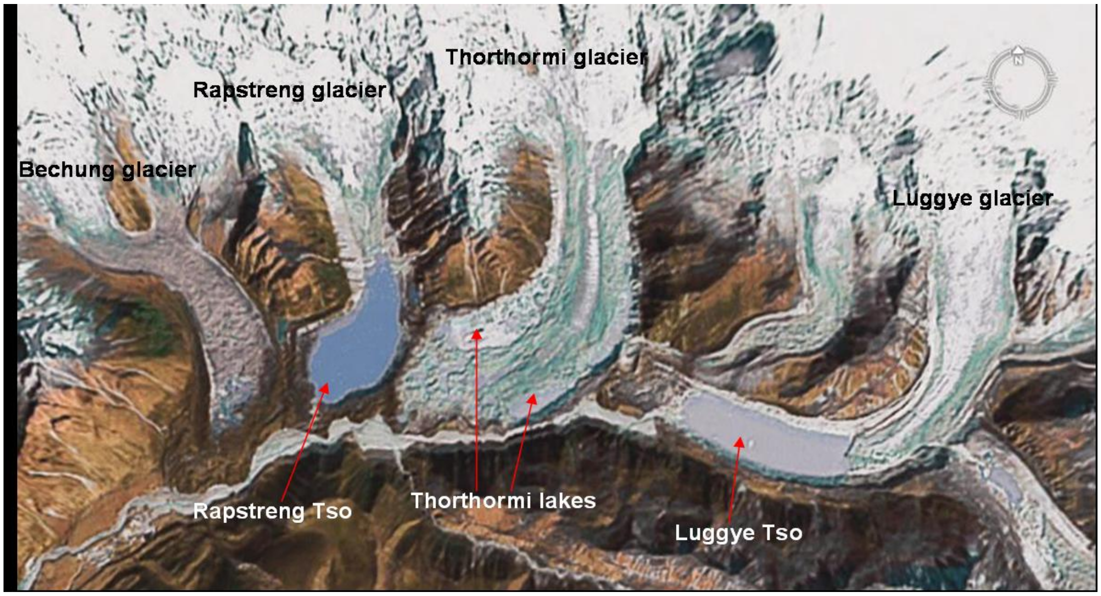


Figure 3: Glaciers and Glacial Lakes in Lunana basin (Source: Google Earth, 2006)

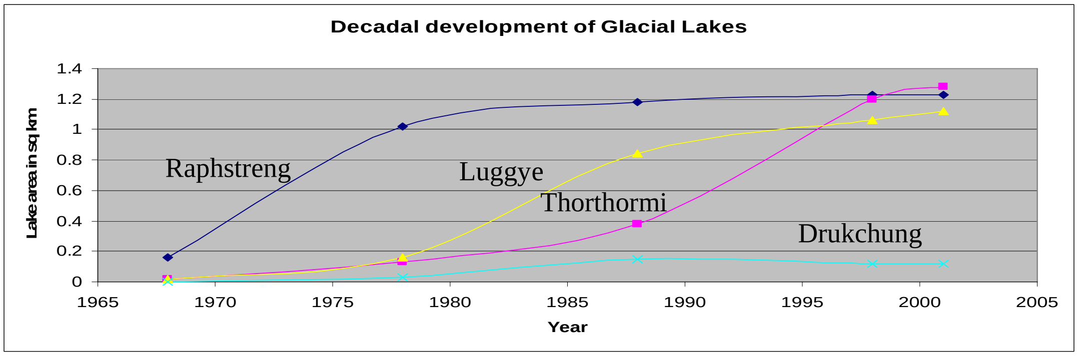
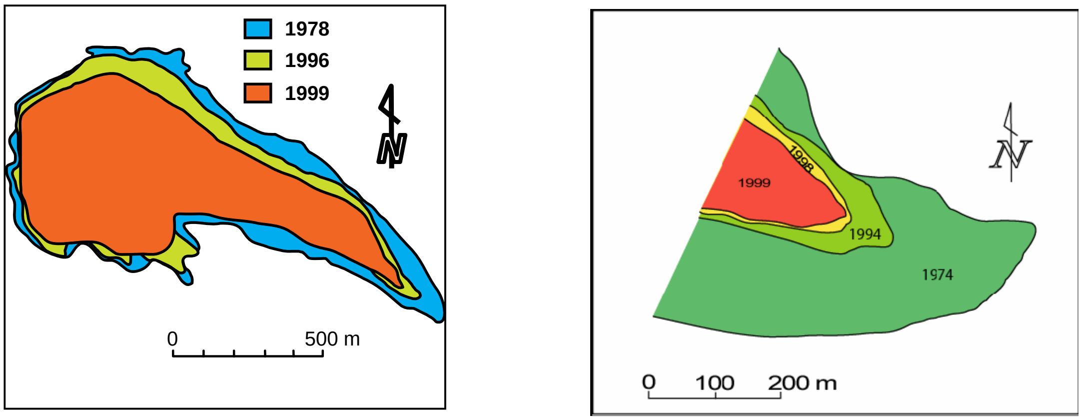


Figure 4: Development of Glacial Lakes in Lunana basin, Bhutan

3.4 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.



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)

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.

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) and the development trend of the Lake is shown in the Figure 7.

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).

Evidences have been conclusive enough to make glacier melting and an important indicator for climate change.

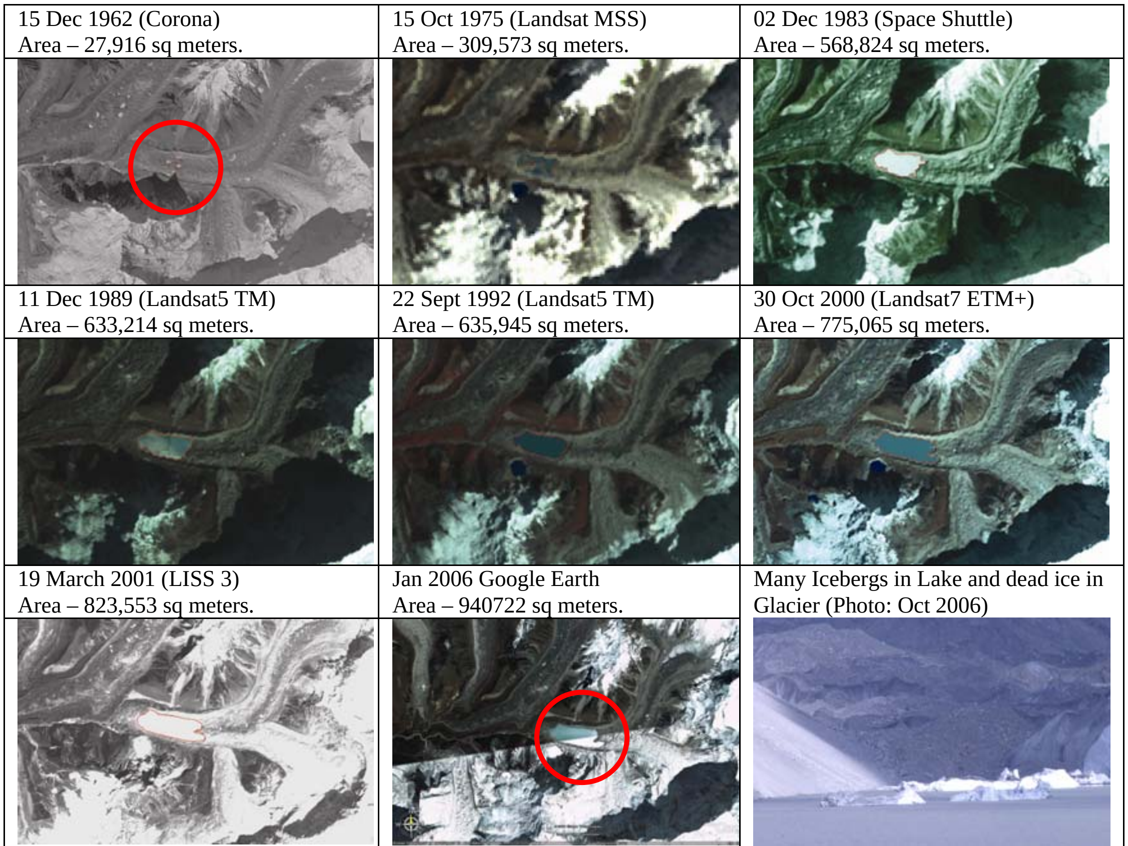
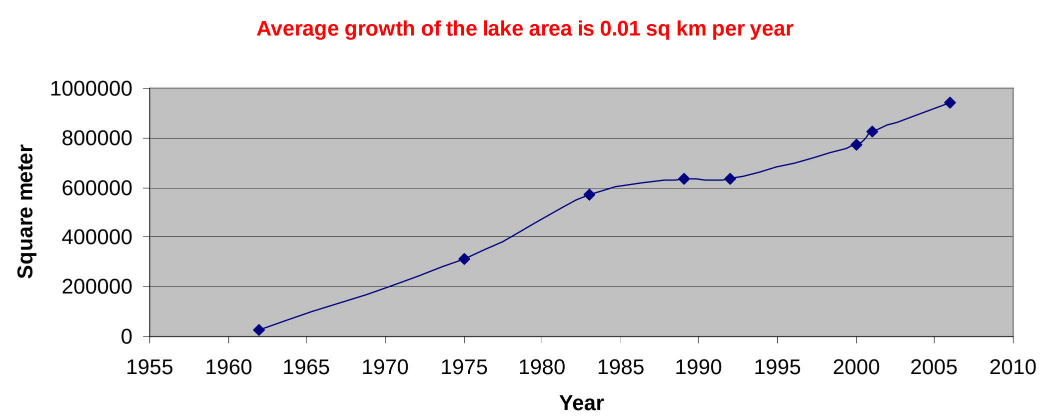


Figure 6: View and aerial extension of Imja Glacial Lake from 1962 to 2006 in different satellite images and field observation.

Figure 7: Development trend of Imja Glacial Lake from 1962 to 2006



4 GLOF IN HIMALAYA WITH TRANSBOUNDARY EFFECT

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.

Table 1: Recorded GLOF events in Hindu Kush-Himalayan Region					
No	Date	Lakes	River Basins	Country Effected	Cause of GLOF
1	Aug-35	Tara-Cho	Boqu / Sun Koshi	China and Nepal	Dam Piping
2	21Sep-64	Gelhaipuco	PumQu / Arun	China and Nepal	Glacier surge
3	1964	Zhangzangbo	Boqu / Sun Koshi	China and Nepal	Piping
4	25Aug-64	Longda	Gyrong / Trisuli	China and Nepal	Not known
5	1968	Ayaco	PumQu / Arun	China and Nepal	Not known
6	1969	Ayaco	PumQu / Arun	China and Nepal	Not known
7	18Aug-70	Ayaco	PumQu / Arun	China and Nepal	Not known
8	3Sep-77	Nare	Dudh Koshi	Nepal	Moraine collapse
9	23Jun-80	Nagma Pokhari	Tamor	Nepal	Moraine collapse
10	11Jul-81	Zhangzangbo	Boqu / Sun Koshi	China and Nepal	Glacier surge
11	27Aug-82	Jinco	PumQu / Arun	China and Nepal	Glacier surge
12	4Aug-85	Dig Tsho	Dudh Koshi	Nepal	Ice avalanche
13	12Jul-91	Chubung	Tama Koshi	Nepal	Moraine collapse
14	3Sep-98	TamPokhari	Dudh Koshi	Nepal	Ice avalanche
15	10Jul-40	Qunbixiama-Cho	Kangboqu-Ahmchu	China	Ice avalanche
16	10Jul-54	Sangwang-Cho	Nianchu	China	Glacier advance
17	26Sep-64	Damenlahe-Cho	Nyang	China	Ice avalanche
18	23Jul-72	Poge-Cho	Xibaxiaqu	China	Ice avalanche
19	24Jun-81	Zari-Cho	Yarlung Zangbo	China	Ice avalanche
20	14Jul-88	Mitui-Cho	Palong Zangbo	China	Ice avalanche
21	7Oct-94	Lugge-Tsho	Pho Chu	Bhutan	Moraine collapse

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.

Some of the GLOF events which occur in Tibet/China had the transboundary effect in Nepal are described here after. The Longda Glacial Lake burst on 25 August 1964. The outburst flood washed out a huge amount of sediment which created a debris blockage 800m long, 200m wide, and 5m deep, on average, along the Gyirongzangbo River, the source of the Trishuli River.

Gelhaipuco is located in the headwaters of the Gelhaipu Gully (Natangqu River Basin), east of Riwo, Dinggye County, Tibet (China) and Arun (Pumqu) River in Nepal. The flood, with a huge amount of debris, damaged Chentang-Riwo Highway and 12 trucks transporting timber were washed away and caused heavy economic losses.

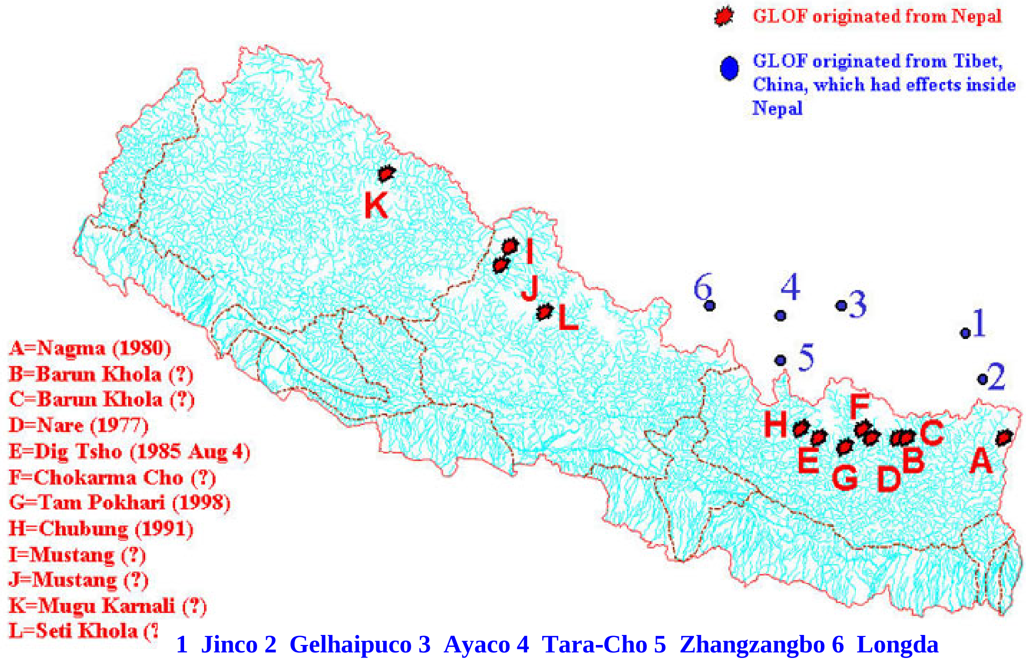


Figure 8: Glacial lake outburst events in the Himalayan region affecting inside Nepal

The Zhangzangbo-Cho is at the headwaters of Poiqu in China and the Bhote-Sun Koshi River in Nepal. The GLOF event was happened on 11 July 1981and the debris flow damaged the highway sections between the outlet of Zhangzangbo Gully and the Sun Koshi Power Station in Nepal. It destroyed the Friendship Bridge of the China–Nepal Highway and the diversion weir at the Sun Koshi hydropower plant in Nepal, causing serious economic losses to Nepal. It also destroyed two bridges and tore out extensive road sections of the Arniko Highway of Nepal amounting to losses of US $3 million.

Ayaco is located at the headwaters of the Zongboxan River in the Pumqu Basin (Tibet) on the northwestern slope of Mount Everest. The flood damaged the highway and concrete bridges of Desha No.1 in Tibet (China). The damage in Nepal side is unknown.

The damage caused by the GLOF event of Jinco and Tara-Cho is not well known. Jinco Lake is located at the headwaters of the Yairuzangbo River of the Pumqu Basin (Tibet) and the Arun Basin in Nepal whereas Tara-Cho Lake is located in the Targyailing Gully of the Boqu Basin (Tibet [China]) and the Bhote Koshi Basin (in Nepal).

Some of the glacial lakes in Poiqu basin in China, which is a trans-boundary basin and join with SunKoshi-BhoteKoshi in Nepal, such as LumuChimi lake and GangxiCo lake. The lakes have grown almost double in size within last twentyfive years (Figure 1). These lakes pose potential threat of GLOFs which most often have devastating effects on local people as well as transboundary.

5 INVENTORIES OF GLACIERS AND GLACIAL LAKES IN 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 9). 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.

Table 2: Summary of Glaciers and Glacial Lakes in Himalayan region compiled by ICIMOD.

River Basins	Glaciers		Glacial Lakes		
	Number	Area (sq km)	Number	Area (sq km)	Potential GLOF
Pakistan Himalaya					
Indus Basin	5218	15040	2420	126.35	52
India Himalaya					
Himachal Pradesh	2554	4160	156	385.22	16
Uttaranchal	1439	4060	127	2.49	0
Tista River	285	576	266	20.20	14
Tibet Autonomous Region, Peoples' Republic of China					
Sub-basins of Ganges	1578	2864	824	85.19	77
Nepal Himalaya					
Nepal	3252	5324	2323	75.70	20
Bhutan Himalaya					
Bhutan	677	1317	2674	106.87	24
Hindu Kush-Himalaya	15,003	33,339	8,790	799.49	203

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

6 CONCLUSIONS

Glacier is one of the key indicator of climate change.

Many warm years after 1990 in the Northern Hemisphere ever since climate statistics have been monitored and documented began in 1861 and expected increase in the global mean temperatures. The amount could be anything from 1.4 to 5.8°C in 2100 depending on the climate model and greenhouse gases emission scenario.

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. Valley Glaciers and small glaciers are retreating faster.

The glacial lakes in the Himalaya are known to have mostly formed within the last 5 decades. As a result of global warming the glacial lakes are increasing in number and size. 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.

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