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The Tam Pokhari Glacier Lake outburst flood of 3 September 1998

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ABSTRACT

Retreating glaciers in the Himalayas have given rise to many glacier lakes. One of such lakes is the Tam Pokhari. It is located in eastern Nepal (86°56'52" E longitude and 27°44'33" N latitude) and breached on 3 September 1998 releasing 17.66 million cubic metres of water. The sediments transported by the outburst flood dammed the Dudh Koshi River and inundated it up to 2 km upstream The nature of the glacier lake outburst flood, its causes, and downstream impact are presented in this paper.

INTRODUCTION

Glacier lakes are formed at the terminus of a glacier. In the Himalayan region, glacier lakes are generally surrounded and dammed by moraines formed in the neo-glaciation period and left in place during the glacier retreat. In Nepal, most of the major rivers are snow-fed. Potentially dangerous glacier lakes in the upper reaches feed some of these rivers. A sudden overflow of lake water or breach of the moraine dam releases a huge amount of water in a short period and results in a glacier lake outburst flood (GLOF).

This paper highlights the present status of glacier lake study in Nepal and presents a case study of the Tam Pokhari GLOF, which occurred on 3 September 1998. The fieldwork was carried out in February and May 1999. The lake was named as the Sabai Tsho in previous reports and maps, but it is locally famous as the Tam Pokhari. Hence, this name is adopted here.

GLACIER LAKE STUDY IN NEPAL

Most of the glaciers and glacier lakes in Nepal are confined to the western and eastern Himalayas (i.e. the Gandaki and Koshi Basins). The glacier lakes of Nepal are broadly classified into moraine-dammed and ice-dammed ones. Out of them, the moraine-dammed lakes are abundant, and the dams are further subdivided into ice-free moraine dams and ice-cored moraine dams (Yamada 1998).

Few had paid attention to the study of glacier lakes and their outburst phenomena prior to 1985 when the first remarkable GLOF of Dig-Tsho destroyed the almost complete Namche Small Hydroelectric Project as well as bridges, trails, and houses in the Dudh Koshi Valley (Galay 1985). Vuichard and Zimmermann (1986 and 1987) studied the Dig Tsho outburst in detail. The Water and Energy Commission Secretariat (WECS) started the GLOF study in Nepal since then. The Japan International Cooperation Agency (JICA) provided the technical and financial assistance to WECS in the earlier stage of the study. The study revealed seven glacier lakes as dangerous ones (Yamada 1993). Among them, the Tsho Rolpa, Thulagi, Imja, and Lower Barun Glacier Lakes were studied in detail. Recently, WECS made a detailed field investigation in the area affected by the GLOF of 3 September 1998 in the Inkhu Valley – a left bank tributary of the Dudh Koshi River.

Realising the fact that the Nepal and Tibetan Himalayas are the main places of development of glaciers and glacier lakes, Chinese and Nepalese scientists formed a Sino–Nepalese Joint Expedition Study Team in 1988 and carried out a detailed investigation of the glacier lakes and past GLOFs. The property loss and damage due to the past GLOFs occurring in this region is summarised in Table 1.

TAM POKHARI GLACIER LAKE

The Tam Pokhari Glacier Lake lies in the upper reaches of the Inkhu Khola in the Khumbu Himalayan region and is located at 86°56'52" E longitude and 27°44'33" N latitude (Fig. 1). The Inkhu Khola is a tributary of the Dudh Koshi River with its confluence at Klimpi in the Solukhumbu District of eastern Nepal (Fig. 2). It takes about 4–5 days' walk from the Dudh Koshi confluence or 3 days' walk from Lukla (the nearest airport) to reach the lake. The lake lies in the trek route to Mera Peak, which is very popular among the trekkers.

Geologically, the lake area falls under the Higher Himalayan Crystalline Zone consisting mostly of gneisses, high-grade schists, and migmatites. There are mainly two moraines around the Tam Pokhari Glacier Lake. One of them (i.e. from the Charpate Glacier) constitutes the dam itself and the other one (i.e. from the Dig Kharka Glacier) rests directly on the eastern end of the dam, thus increasing its stability (Fig. 2).

The morainic deposits are composed of very lose pebbly sand matrix with minor clay portions along with large

Table 1: Past GLOFs in Nepal and Tibet

S. N.	Date	Name of the lake	Major river basin	Sub river basin	Longitude	Latitude	Remarks
1	15th century	Lake in the Machhapuchhre	Seti River				Pokhara Valley was filled by > 60 m thick with big boulder
2	August 1935	Taraco Lake	Poiqu (Bhote-Sun Koshi) Basin	Targyailing Gully	86° 07.90'	28° 17.49'	Wheat field destroyed, several yaks lost
3	1964	Longda Glacier Lake	Trishuli River Basin	Gyirongzango			
4	1964	Zhangzangbo	Poiqu (Sun Koshi) Basin	Zhangzangbo Gully	86° 03.16'	28° 04.62'	Destroyed highway, intake of Sun Koshi Hydroelectric Project
5	21 September 1964	Gelhaipu Co	Pum Qu (Arun) Basin	Natang Qu, Gelhipu Qu	87° 48' 43.84"	28° 12' 32.4"	
6	1968–1970 Three times	Ayaco or Ayico	Pum Qu (Arun) Basin	Zangboxan River	86° 29'	28° 21'	4.59 million m^3 of sediment deposited
7	3 September 1977	Nare	Dudh Koshi	Imja Khola	86° 50'	27° 50'	Mini hydro, bridges, and farmland destroyed
8	25 July 1980	Nagma Pokhari	Tamor Basin	Yangma Khola	87° 51' 58.14"	27° 52' 3.13"	One village destroyed and people migrated
9	11 July 1981	Zhangzangbo 2nd time	Poiqu (Sun Koshi) Basin	Zhangzangbo Gully	86° 03.16'	28° 04.62'	Highway, intake of the Sun Koshi Hydroelectric Project destroyed
10	27 August 1982	Jinco	Pum Qu (Arun)	Yairu Zangbo	87° 38' 43.7"	28° 12' 32.4"	8 villages affected and 1,600 heads of livestock lost
11	4 August 1985	Dig-Tsho	Dudh Koshi	Langmoche Khola	86° 35' 18"	27° 52' 30"	The Namche Hydroelectric Project collapsed, 14 bridges, trails, and agricultural land destroyed
12	12 July 1991	Chubung	Tama Koshi	Rolwaling Khola	86° 27' 41.2"	27° 52' 31"	Houses and farmland destroyed
13	3 September 1998	Tam Pokhari	Dudh Koshi	Inkhu Khola	86° 56' 52"	27° 44' 33"	5 bridges, agricultural land destroyed, 2 persons killed

Source: (Galay 1985; LIGG. WECS, NEA (1988); Damen 1992; and Dwivedi et al. 1999)

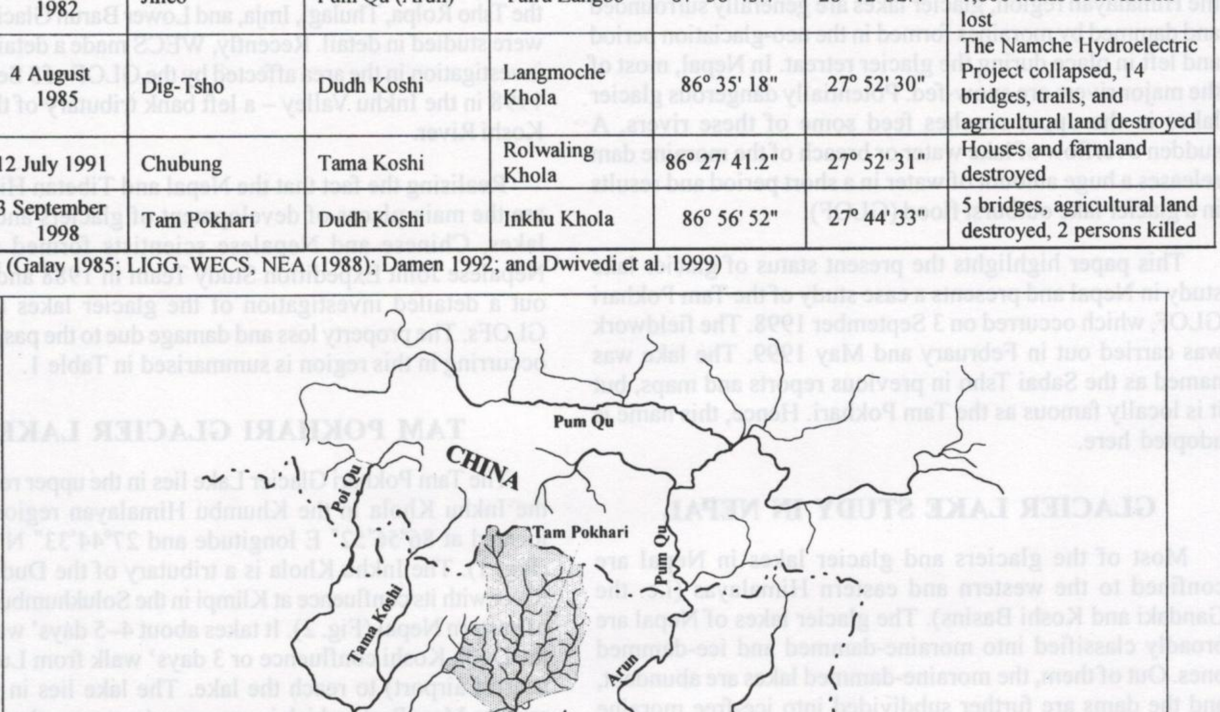

Fig. 1: Location map of the study area

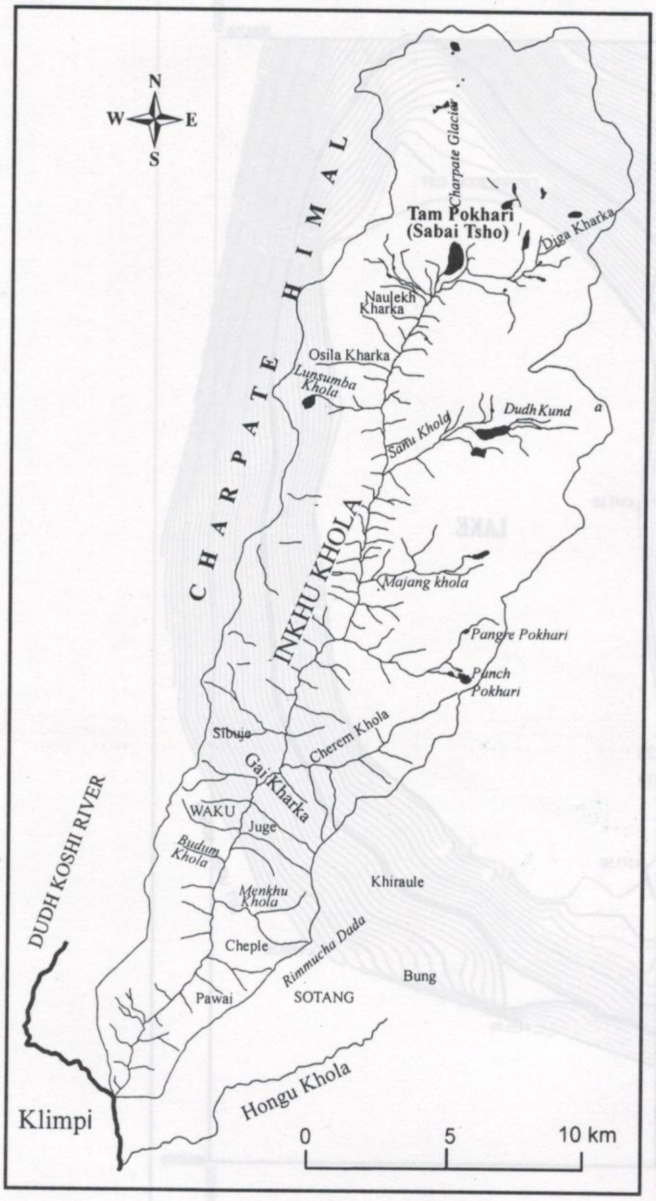

Fig. 2: The Inkhu Khola Watershed

boulders and cobbles of gneiss and schist. The height of the lowest part of the end moraine was about 5 m from the water level before the outburst. There is a rock cliff in the northwestern corner of the lake (Fig. 3). The approximate gradient of the glacier feeding the lake is 45°.

CONDITION OF THE LAKE BEFORE OUTBURST

The lake was categorised as a dangerous one by Vuichard and Zimmermann (1987). Yamada (1993) carried out further studies by flying over the lake in 1992. The other sources of information are the topographical maps, satellite images, aerial photographs, and photographs taken by Vuichard and Zimmermann in 1986 and Yamada during his flight in 1992. Here, an attempt is made to estimate the variation of the lake area before the outburst from different sources, which are as follows:

- Topographical map (on the scale of one mile to the inch), published by the Survey of India in 1963 = 0.1311 km^2;
- Planimetric map of satellite image (on 1: 250,000 scale), published in 1986 = 0.3583 km^2;
- Topographical map prepared by Schneider (on 1: 50,000 scale), published in 1987 = 0.5075 km^2;
- MOS-1 satellite image of NASDA taken in November 1990 = 0.4886 km^2;
- Topographical map prepared by the Department of Survey, HMG/Nepal (on 1: 50,000 scale) based on the 1992 aerial photographs = 0.4840 km^2; and
- Field survey organised by WECS in 1999: a) area of the lake before the outburst (measurements based on the watermark) = 0.43575 km^2, and b) area of the lake after the outburst = 0.2433 km^2.

From the above data, it is evident that the lake area was reduced twice: i.e. between 1987 and 1990, and between 1992 and 1998. Some scouring of the end moraine can also be seen on the photographs taken around 1996 (Plate 1). Hence, it is inferred that there had already been some instances of overtopping of the end moraine before the outburst.

Plate 1: Scouring seen on the end moraine *(indicated by the box and arrow). Photograph made available by Mrs Saskia Clark.*

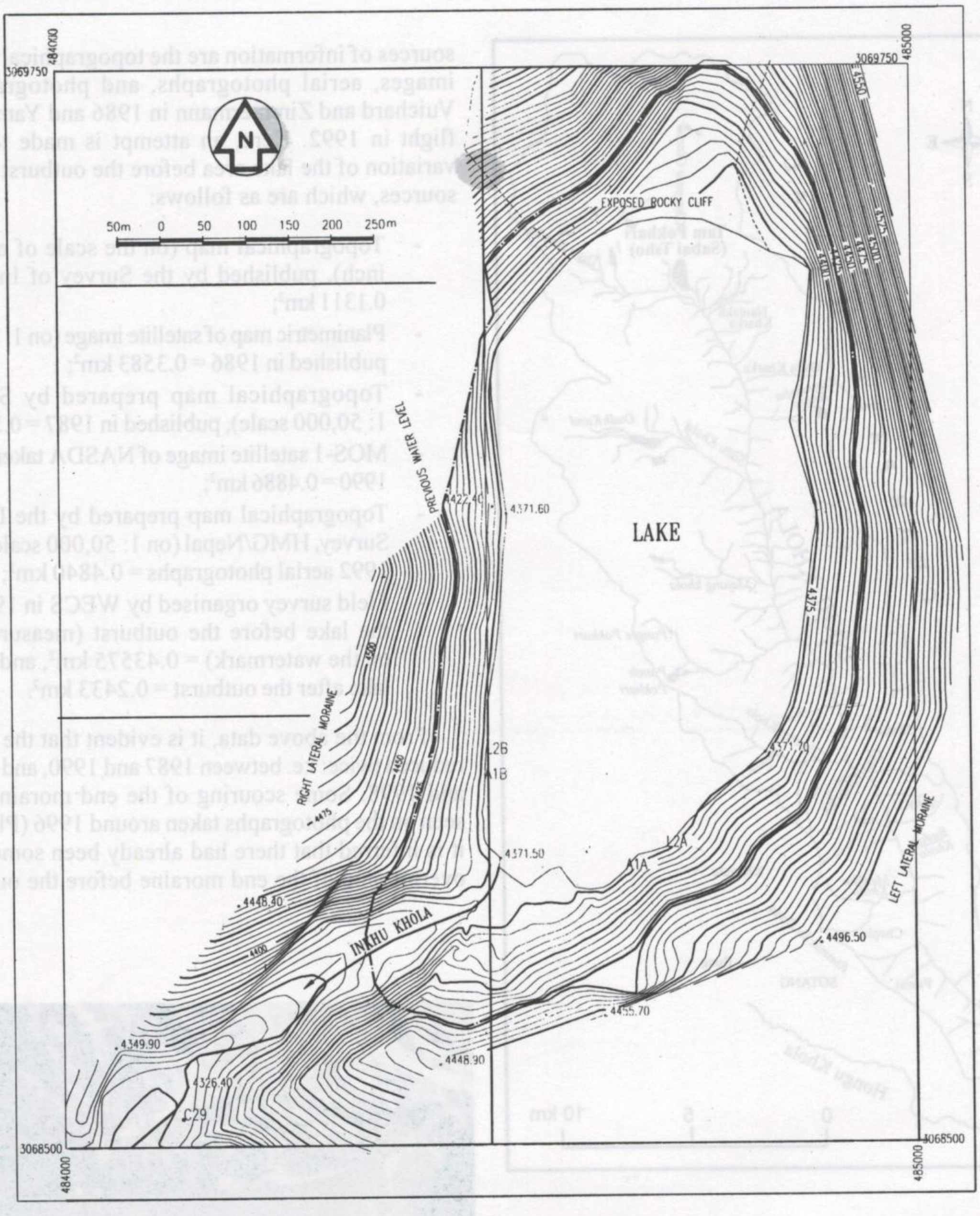

Fig. 3: Topographical map of the Tam Pokhari Lake

OUTBURST FLOOD OF 3 SEPTEMBER 1998

The people sleeping in the seasonal settlement Thagnak, which is just about 500 m downstream of the lake, were awakened by a very loud noise at 5 a.m. of 3 September 1998. It was the noise of snow avalanche from the hanging glacier into the Tam Pokhari Lake. When they came out of their houses, they saw the water of the lake rising high (about 5 m) above the end moraine of the lake, and the breaching of the moraine dam followed subsequently. Mr Lakpa Galzen Sherpa, resident of Lukla and the owner of a seasonal teashop, luckily had a loaded camera at that time and took some snaps of the breaching process of the end moraine (Plate 2). The photographs indicate that the breach did not occur at once. It appears that a large volume of ice plunged into the lake and huge waves triggered off the breach. The surge first scoured the outer lower portion of the dam, and then the failure propagated inwards. In this process, the breached section was widened by side fall, resulting in the formation of a deep and wide channel. The people saw a huge amount of muddy water with floating large boulders and tree trunks moving rapidly downstream. Three teashops and potato fields of Thagnak were swept away by the GLOF.

The whole Inkhu Valley experienced vibration like an earthquake. In the lower reaches of the Inkhu Valley and in the Dudh Koshi Valley, the flood either eroded away or covered thousands of hectares of valuable rice field. Lateral erosion triggered landslides at many places. The casualties and property loss by the GLOF are presented in Table 2.

Plate 2: Breaching of the end moraine of the Tam Pokhari Glacier Lake. *Photographed by Mr Lakpa Galzen Sherpa at 8 a.m. on 3 September 1998.*

Table 2: Casualties and property loss by the Tam Pokhari GLOF (Dwivedi et al. 1999)

Districts	Human casualties	Bridges		Gauging station	Total loss of property (US $ 1= NRs 68.70)	Remarks
		Suspension or Suspended	Wooden			
Solukhumbu	1	3	2		Rs. 91,535,330.00	
Khotang	Unavailable	Unavailable	Unavailable	Unavailable	Unavailable	
Okhaldhunga	1	Silaute Ghat and one bridge partly damaged		1	Rs. 59,123,600.00	Cost of bridges not included
Udaipur	None	Not reported	Not reported	None	Not reported	

The total volume of water released from the lake was 17.66 x 10^6 m^3. According to the eyewitnesses, the discharge from the lake became normal after 3 days.

The maximum depth of the lake is estimated at 60 m. After the outburst, the water level of the lake decreased by 52 m. Present surface area of the lake is 0.24722 km^2. The average height of the moraine from the present lake level is 133 m. The average inner slope of the moraine is 60° near the glacier and 32° near the end moraine. The average cut slope of the breached section of the end moraine is 45°. The ice from the tongue of the Charpate Glacier is still falling into the lake (Plate 3). A small stream is flowing from the lake into the Inkhu Khola.

The GLOF reached the Dudh Koshi confluence (situated 34.96 km downstream of the lake at an altitude of 875 m), after 2 hours at 7:10 a.m. In this section, it travelled with an average velocity of 5 m/sec. The slower velocity is due to the narrow but tortuous section of the river and the gorges present in the river course. Other factor to reduce the velocity was the viscosity exerted by the debris, which contained boulders up to 10 m in diameter. After the flood entered in the Dudh Koshi, the velocity increased to 10 m/sec. The flood reached the Rabuwa Bazaar in the Okhaldhunga District (Gauging Station No. 670), which is about 31 km downstream of the confluence, at 8 a.m. The flood washed away the hydrological station. The water flowed above the 10 m gauge at this station. The flood subsequently reached Hampuwachaur (Gauging Station No 680) in the Sun Koshi River and Chatara Kothu in the Sapta Koshi River (Fig. 1) at 9 a.m. and 9 p.m., respectively. From Rabuwa to the Sun Koshi, the velocity remained about 7 m/sec. But it travelled along the Sun Koshi River as an ordinary high flood. The highest water level was observed in the Koshi Barrage, near the Indo-Nepal boarder at midnight. The river maintained its original discharge only after three days.

Cause of the avalanche

There were assumptions that an earthquake had triggered the avalanche. But the earthquake records of the National Seismological Centre, Department of Mines and Geology (Table 3) do not support the idea. There was a tremor at 10:35 p.m. on 2 September of M = 3.46 about 14 km northeast

Table 3: Local Seismic Bulletin from 29 August to 3 September 98 (M. R. Pandey, personal communication 1999)

Data	Time origin UTC	°E latitude	Error_latitude (δ lat.)	°N longitude	Error_longitude (δ long.)	Magnitude Richter scale	Error magnitude (δ mag.)
29/8/98	2 h 36 m 14.71 s	27.36	1.63	86.06	2.48	3.35	0.37
29/8/98	6 h 3 m 50.55 s	27.33	1.43	86.05	2.08	3.15	0.39
29/8/98	14 h 16 m 41.98 s	27.43	1.30	86.89	1.96	3.87	0.26
30/8/98	3 h 24 m 56.72 s	27.31	1.60	86.01	2.36	3.14	0.35
2/9/98	8 h 6 m 33.25 s	27.45	2.65	86.90	6.89	3.05	0.37
2/9/98	16 h 50 m 0.00 s	27.81	2.01	86.97	3.34	3.46	0.24
3/9/98	0 h 4 m 44036 s	27.82	1.03	86.98	1.71	3.77	0.27
3/9/98	11 h 25 m 12.31 s	27.76	2.02	86.92	2.96	3.36	0.30
3/9/98	14 h 30 m 3.47 s	27.79	3.35	86.97	9.20	3.11	0.73
Local time = UTC + 5 hrs 45 min							

of the lake. It is not likely that this tremor caused the avalanche 6 hours 25 minutes later. Other tremor of M = 3.77 was recorded at 5: 25 a.m. on 3 September. But, it was already after the avalanche and its epicentre was at the Panch Pokhari, where five glacier lakes are located.

There was a huge mass of ice accumulated on the steep slope of the hanging glacier (Plate 4). The weight of the ice exceeded the resisting force and the resulting avalanche fell directly into the lake. The fact that frost action weakened the rock beneath the glacier cannot be ruled out. Though this was not the first time that the avalanche occurred, but it was large enough to trigger the GLOF.

SITUATION IN THE INKHU VALLEY

The Inkhu Khola captures the discharge of the Tam Pokhari Lake and has a catchment area of 307.5 km^2. The distance between the lake and the confluence of the Inkhu Khola and Dudh Koshi is 34.96 km with average gradient of 6°. There are several colluvial fans extending from the steep mountain slopes on both sides of the valley. Even a small tributary has formed a large fan, as the gradient of the tributaries of the Inkhu Khola is very high. Such fans were truncated by the GLOF and have vertical slopes. Most part of the valley slope is covered by dense forest, except the upper reaches of the Sanu Khola (Fig. 2).

The sediments transported by the GLOF dammed the Dudh Koshi River and inundated it up to 2 km upstream (Plate 5). About 12 m high sediment terrace was observed in the Dudh Koshi River (Plate 6). According to the inhabitants near the Dudh Koshi confluence, the river level was raised by approximately 30 m. It is reported that this temporary damming of the Dudh Koshi River was opened up during the monsoon of 1999 (i.e. in July-August 1999).

The first surge of flood eroded and shifted the sediments further downstream. But, as the velocity of the peak flood started receding, the sediments en route were dropped down and the riverbed level was raised again. During the field study, intermittent damming and subsequent breaching effects were noticed in many places along the valley. Some earlier very large boulders that were scattered in the valley were reworked by the GLOF. One such boulder is plugged in the narrow gorge upstream of Gaikharka and was responsible for the changed river profile of the Inkhu Khola.

Plate 3: The lake and the hanging glacier after the outburst *(see also Plate 4).*

Plate 4: The hanging glacier and the lake before the outburst of 3 September 1998. *Photographed by Mr Dawa Galzen Sherpa.*

Plate 5: The temporary lake formed in the Dudh Koshi River by the GLOF of 3 September 1998. The GLOF came from the lower-right corner of the photograph.

Plate 6: The sediment accumulated near the confluence of the Dudh Koshi by the GLOF. The earlier river course was about 5 m deeper than the present water level *(height of the person standing is 1.63 m).*

Socio-economic impacts

Though the casualties by the GLOF are low, its socio-economic impacts are immense. There is no road network in the flood-affected areas. Hence, the trails and suspension bridges play a vital role in the daily life of inhabitants. The flood swept away four suspended and suspension bridges and one is partly damaged. The valley is very narrow in many places and there were trails on either side, especially upstream of the Mojang Khola, before the burst. At present, there are no continuous trails along the valley. The remaining trails are truncated in the vertical cliffs scoured by the GLOF. This has interrupted the movement of people and goods. Though the people have constructed temporary bridges made up of wood and bamboo, these will last only up to the next monsoon.

The villagers used the upper reaches of the Inkhu Valley as a good summer pastureland for yak and sheep. It is now almost impossible to bring the animals to these pastures. The trekkers to Mera Peak are also facing difficulties in finding the trails to Thagnak.

In the lower reaches of the Inkhu Khola and Dudh Koshi, the flood either eroded away the rice fields or covered them with sediments. As the flood occurred just before the crop harvesting time, the loss was quite significant.

Environmental impacts

The entire river course of Inkhu and lower reaches of the Dudh Koshi suffered seriously by the GLOF. In the upper reaches of the Inkhu Khola, the river has deepened up to 10 m giving rise to vertical bank cuttings. These destabilised slopes will contribute huge amount of sediments in the years to come. At some places, the flood has cut the toe of old landslides and reactivated them. What used to be green forestlands, camping grounds, and fields before the GLOF, were turned into the sea of boulders and sediments.

CONCLUSIONS

The Tam Pokhari Glacier Lake located in eastern Nepal breached on 3 September 1998. There was a huge mass of ice accumulated on the steep slope of the hanging glacier and it triggered an avalanche that fell directly into the lake. The resulting GLOF caused severe damage in the Inkhu Khola and the lower reaches of the Dudh Koshi River. A sudden release of 17.66 million cubic metres of water washed away four suspended and suspension bridges as well as the valuable agricultural land lying on both banks. The GLOF dammed the Dudh Koshi River and inundated it up to 2 km upstream. It also interrupted the movement of people and goods.

A comprehensive study and regular monitoring of the dangerous glacier lakes is necessary for the sustainable development of water resources and other related fields, and also for predicting such types of natural disaster in the entire Himalayan Range.

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