GLACIER LAKE OUTBURST FLOODS AND DEBRIS FLOW DISASTERS IN TIBETAN PLATEAU

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ABSTRACT

End moraine dammed lake and glacier dammed lake outburst floods(EMDLOFs and GDLOFs) are the most important disasters related glacier in China. The former happen mainly in Tibet, and the latter occur principally in the Xinjiang Province. Great EMDLOFs have been reported 19 times since 1935, and recorded GDLOFs are now 30 since 1956. EMDLOFs are closely associated with ice avalanches, and 81 % of all failures of the dams occur during July to August when ice avalanches occur frequently. GDLOFs often occur in years of the highest air temperature, and 63.3 % of all failures are between August and September when the storage capacity of the glacier lake reaches maximum. Whether the end moraine dammed lakes are of potential danger depends on the flow of the glacier that feeds the lake and the vertical distance between the terminus of the glacier and the level of the lake.

INTRODUCTION

Glacier lakes of various sizes and shapes are widely distributed in the alpine regions of Tibetan plateau where the present glaciers are situated. Catastrophic outbursts from glacier lakes, produced by various causes, occur frequently in these regions. Most of them have been ignored as they happened in untraversed regions. However, the known catastrophic outburst from glacier lakes, as well as meltwater floods and debris flows, have caused severe damage with respect to life and property, farmland, water conservancy, communications, transportation, etc. (Ding, 1992). With the development of communication and transportation, farming and animal husbandry in the west of China, the disasters which are brought about by glacier lake outburst floods and debris flows have seriously affected life and property and economic reconstruction of these regions. Therefore, it is important and urgent to understand the distribution of the dangerous glacier lakes and in order to study the causes of their bursts and to promote preventive measures. Hence, catastrophic outburst from glacier lakes have been brought to the attention of scientists, and various types of outburst disasters have been reported and studied during the past decades (Hewitt, 1982; Lu and Li, 1986; Liu and Sharmal, 1988; Xu, 1987; Xu and Feng, 1988, 1989; Zhang and Zhou, 1990; Ding and Liu, 1992).

DISASTERS FROM THE BURST GLACIER LAKES

Up to the present, outburst from lakes dammed by end moraines happened most frequently in the middle section of the Himalayas (Table 1). Twenty one outburst from lakes dammed by end moraines have been investigated since 1935. For example, catastrophic outburst from glacier lakes in the Himalayas in 1954 inundated hundreds of residential areas, including the cities Xigaze, Gyangze and Yadong and a number of farmlands, water conservancy and traffic facilities. After the Damenhai glacier lake burst in Gongbogyernde county in 1964, the outburst flood rushed down with the speed of 10 m/s from 5120 m a.s.l., headed direct to the mouth of a channel at about 3400 m a.s.l. and lashed at the side of the Niyang River. The outburst debris flow piled up a dam in the valley of the Niyang River, 20 m high, 850 m long and 150 wide at the top, which obstructed the Niyang River for about 10 hours. The flood destroyed the Sichaun-Xizang highway, cut off the traffic for 20 days, inundated most of four pasturelands, and washed away a lot of trees on both sides of the gully. In 1981 the Zhongzangbo glacier lake burst and debris flow in the Nyalam county smashed the highway in arrange of 50 km between the outlet of Zongzangbo gully and the Sun Kosi Power Station in Nepal. In 1982 the Jinco glacier lake burst flood submerged eight villages and a large number of fields, and more than 1600 livestock were killed. In 1984 the Erkuran glacier lake of the Gez river basin burst and outburst flood and debris flow blocked the Gez river and damaged the China-Pakistan highway and a bridge.

Table 1 History of outbursts from lakes dammed by end moraines (Ding and Liu, 1992; Xu and Feng, 1989;)

Lakes	Longitude	Latitude	M / D / Y	F/D	Cause	Maintains/River-systems
Zhanlonba			1902	F/D		Nyainqentanglha/Yiongzhangb R.
Taraco	86°07'54"	28° 17'29"	8 / 28 / 35	D	IA	Himalayas/Poiqu River
Qubixiama	85° 02'24"	27° 42'30"	6 / 10 / 40	F	IA	Himalayas/Upper Kangma R.
Xingguolonba			1950	F		Nyainqentanglha/Niyang R.
Sangwang	90° 40'00"	28° 24'54"	7 / 16 / 54	F	IA	Himalayas/Upper Nyangqu R.
Hailuogou	102° 00'00"	29° 32'00"	7 / ? / 55	D		Hengdaun/Upper Yalong R.
			7 / ? / 66	D		
			8 / 30 / 76	D		
Zhangzangbo	85° 51'25"	28° 10'38"	7 / ? / 64	D		Himalayas/Poiqu R.
			7 / 11 / 81	D		
Guangxieco	96° 34'	29° 25'	7 / ? / 64	D		Nyainqentanglha/Niyang R.
Longda	85° 00'25"	28° 24'46"	8 / 25 / 64	F/D	IA	Himalayas/Trisuli R.
Gelhaipu	87° 48'31"	27° 57'50"	9 / 21 / 64	D	IA	Himalayas/Pumqu R.
Damenhai	93° 09'15"	29° 56'20"	9 / 26 / 64	D	IA	Nyainqentanglha/Niyang R.
Ayaco	86° 29'33"	28° 20'49"	8 / 15 / 65	D	IA	Himalayas/Pumqu R.
			8 / 17 / 69	D	IA	
			8 / 18 / 70	D	IA	
Bugyai	94° 48'36"	31° 46'20"	7 / 23 / 72	F		Nyainqentanglha/Nujiang R.
Zari	90° 48'30"	28° 22'50"	6 / 24 / 81	F/D	IA	Himalayas/Pumqu R.
Zirema	86° 03'54"	28° 04'36"	7 / 11 / 81	F/D	IA	Himalayas/Poiqu R.
Jinco	87° 38'29"	28° 11'39"	8 / 27 / 82	D	IA	Himalayas/Pumqu R.
Gule	94° 30'00"	29° 30'00"	7 / 15 / 88	D	IA	Nyainqentanglha/Berongzhongbu

M/D/Y=Month/Day/Year, F/D=Flood/Debris flow, IA=Ice avalanche into the lake.

TYPES AND DISTRIBUTION OF THE BURST GLACIER LAKES

Two types of potentially dangerous glacier lakes are known in China. One is an end moraine and the other is the lake dammed by glacier. Outbursts form lakes dammed by end moraines occur in the Himalayas, the Middle and eastern of Nyainqentanglha mountains and the sections of Hengdaun mountains (Figure 1). The dams of the end-moraine lakes are made up of various terminal moraines that formed since the Little Ice Age, of which the youngest moraine lakes, which are close to the present glaciers, are the most dangerous.

Outburst from glacier-dammed lakes are mainly scattered over the Karakorum mountains, the Pamir and the west of the Tien Shan in the west of China. The famous glacier-dammed lakes, the Taramkangri Lake and Kyagar Lake, are situated at the upper reaches of the Yarkand river in the Shaksgam valley. The Taramkangri and Kyagar Glaciers, both located on the north slopes of the Karakorum, extended down to the Shaksgam valley and have dammed up two lakes, 5 km apart (Table 2). These two glacier lakes have burst repeatedly, as recorded at Kaqung hydrological station at the outlet of the Yarkand river since 1954. Up to now, more than 30 outbursts from glacier-dammed lakes have been

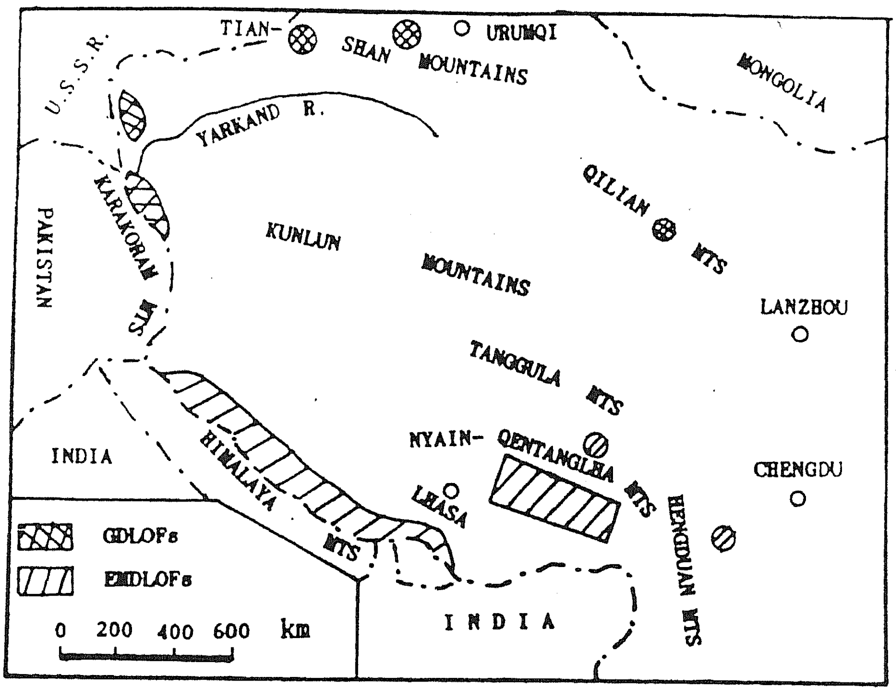

Figure 1 Distribution of floods from glacier-dammed lakes (GDLOFs) and floods from lakes dammed by end moraines (EMDLOFs).

Table 2. Data for Taramkangri and Kyagar Lakes (Zhang and Zhou, 1990)

Lake	Altitude m a.s.l.	Length km	Width m	Volume $10^8 m^3$	Maximum depth m	Length of Barrier Km
Kyagar	4836	4.93	398	0.60	85	1.5 1976-1987
	4900	9.48	638	3.15	155	Postglacial Maximum
Taramkangri	4650	5.25	500	0.96	70	3.8 1976-1987
	4672	7.41	610	1.92	90	Postglacial Maximum

recorded since 1956, of which there have been 20 times in the Yarkand River, the Karakorum, six in the Kunmalike River, Tien Shan mountains, three in the Sikeshu River, Tien Shan mountains, two in the Gez River, the Pamir and one in the Qilian mountains.

Glacier lakes liable to outbursts are distributed mainly over the mountainous border regions of QinghaiXizang Plateau where there are frequent neotectonic movements and high altitude. The highest concentration of outbursts from lakes dammed by end moraines is found in the Middle Himalayas around the Mount Everest. The region where outbursts from glacier-dammed lakes occur frequently is in the Karakorum where the second highest peak in the world, Mount Qogir, is located. Similar lakes in China are mostly situated between 4500 and 5200 m a.s.l. Their areas are under 3 km^2 for the largest ones and only 0.01 km^2 for the smallest ones.

INVESTIGATIONS OF OUTBURSTS FROM GLACIER-DAMMED LAKES

The mechanism of an outburst is complicated, but the external factors that trigger it are obvious. When a glacier lake can store water, its level will rise with increasing glacier ablation. Consequently, outbursts from glacier-dammed lakes often occur in years of the highest air temperature (Figure 2). The volume of most of outbursts is between 1000 and 3000 m^3s^{-1}. The reason why four of the floods reached peaks between 5000 and 6000 m^3s^{-1} is because two ice-dammed lakes, Taramkangri and Kyagar, burst at the same time. Three of the four largest floods in the Yarkand River, and all floods in the Kunmalike River, happened between August 20 and September 30, which is over a month later than the maximum ablation period in July. Failure of the dam happens mostly between August 20 and September 30 when the storage capacity of the glacier lakes reaches a maximum (Table 3). It might be postulated that the catastrophic outbursts from glacier-dammed lakes can be predicted on the basis of weather forecasts, when satellite images show that the lakes have reached their maximum area.

In general, the ice dams are not frozen to their bed, water from the lake does not flow over the dam, and the lake drains through subglacial channel. After the outburst, the dam forms again.

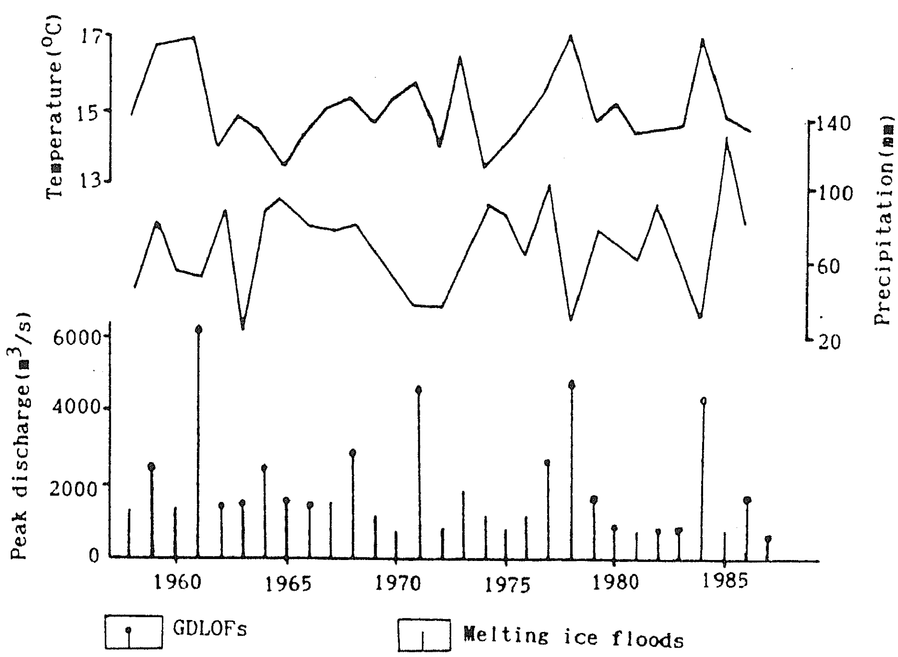

Figure 2 Peak discharge of glacier outbursts of the Yarkand River at kaqun station, mean air temperature in Summer and annual precipitation at Tashikurgan station (3090) m a.s.l). GDLOFs are floods from glacier-dammed lakes.

Table 3. Timing of outbursts from glacier-dammed lakes and outbursts from lakes dammed by end moraines (Ding and Liu, 1992)

Date	Outbursts from glacier-dammed lakes		Outbursts from lakes Dammed by end moraines	
	Number	%	Number	%
July to 20 August	7	23.3	13	61.9
20 August to 30 September	14	46.7	6	28.6
after 30 September	7	23.3	0	0
before 1 July	2	6.7	2	9.5
total	30	100	21	100
July	2	6.7	10	47.6
August	11	36.7	7	33.4
September	8	26.6	2	9.5
others	9	30.0	2	9.5
total	30	100	21	100

POTENTIALLY DANGEROUS END MORAINE DAMMED LAKES

An end-moraine dam is different from a marginal glacier dam. The latter is composed of ice which easily melts and cracks, but the former is composed of till of various sizes and is normally much more stable than the ice dam. An inventory of existing glacier lakes of the Pumqu and Poiqu Rivers in Himalayas have been made by a Sino-Nepalese expedition investigating glacier lake outburst in Himalayas in 1988 (Table 4). Only 3.7 % of the total number of the glacier lakes and 7.2 % of the end moraine-dammed lakes are dumping glacier lakes.

Table 4. Glacier lake inventory in the Poiqu and Pumqu basins (Liu and Sharmal, 1988)

Type of lake	Lakes		Lakes		Lakes		Mean	Mean	Mean
	number	% of total	area km^2	% of total	Volume km^3	% of total	area km^2	volume km^3	depth m
Cirque	86	31.6	6.56	11.7	0.066	4.4	0.076	0.77	10
Trough valley	47	17.3	12.47	22.2	0.312	20.7	0.265	6.63	25
end moraine-dammed	139	51.2	37.09	66.1	1.124	74.9	0.267	8.09	30
total	272		56.11		1.501				

The following morphological features characterize the dangerous end-moraine dams: it has closed lake basin, a height of dam over 80 m, a ratio of dam height to the top width less than 0.6, an angle of slope of the outside of the dam of about 23^0 and a water depth at dam over one-third of its height (Xu and Feng, 1989). Further, the dam contains ice core that may reduce their stability. However, a static pressure maintained by the lake is still not high enough to burst the dam without an additional external action being exerted. The investigated outbursts from lakes dammed by end moraines were all induced by ice avalanches that came from the glaciers feeding the lakes. In each case, an ice avalanche dropped suddenly into the lake and swift and violent waves traveled down the lake, creating breaches in the dam. Because an ice avalanche is associated closely with melting of ice, the periods of maximum ablation also are those of frequent ice avalanches. Hence, 81.0 % of all failures of the dams occur during the hottest months of July and August (Table 3).

Whether or not the end moraine-dammed lakes are dangerous depends on the flow of the glacier that feeds the lake. In an advancing glacier, the glacier tongue is so steep that many cracks develop and ice avalanches are easily produced. Ice avalanches falling into the lake will create waves of huge surging pressure to the dam wall. On the other hand, when a glacier extends down into the lake along a gentle slope, ice sliding into the lake creates small pressures to the dam wall. The areas of the glaciers above the end-moraine lakes are usually between 1.5 and 5.5 km^2 and the glaciers are between 1 and 4 km long. The glacier tongue is generally located in a steep depression or a valley, with the lower part in an extended state, so that cracks tend to form. Thus, it is important to understand recent development and morphological features of the glacier to determine whether an end moraine-dammed lake is of potential danger. Table 5 shows some typical end moraine-dammed lakes in the middle Himalayas of China. It can be seen that the potentially dangerous lakes have a larger lake area and smaller glacier area, a shorter distance from the glacier terminus to the lake and a steeper angle of slope to the glacier tongue than the stable, not dangerous lakes.

Table 5. Comparison of dangerous and stable moraine-dammed lakes in Himalayas (Ding and Liu, 1992)

	Lake			Glacier			
	altitude m a.s.l.	area km^2	Distance to glacier M	terminus elevation m a.s.l.	Length km	area km^2	average slope %
Dangerous:							
Jinco	5350	0.550	0	5350	3.8	3.24	34.4
Coxar	5420	0.660	0	5440	2.8	3.43	23.6
Ahamachimaico	5470	0.565	0	5200	3.8	1.66	15.7
Paquco	5300	0.506	0	5320	4.0	5.40	17.8
Stable:							
Dongyico	4980	0.04	600	5800	3.1	5.25	18.5
Zonbuxan No.13	5320	0.198	0	5360	12.5	24.39	7.2
Kada No. 13	5570	0.191	300	5460	8.0	14.49	11.0
Zongbuxan No.2	5670	0.072	300	5750	5.0	4.96	5.1

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