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Volume change of Imja Glacial Lake in the Nepal Himalayas

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ABSTRACT

Bathymetric surveys were carried out at a 10-year interval (1992 and in 2002) on the Imja Glacial Lake in eastern Nepal, in order to reveal its rate of volume expansion. The lake area, average depth, and stored water were 0.60 km^2, 47.0 m and 28.0×10^6 m^3, respectively, in 1992, and 0.86 km^2, 41.6 m and 35.8×10^6 m^3, respectively, in 2002. The volume of the lake in 2002 was approximately 30% larger than in 1992, and the volume expansion rate was 78×10^4 m^3a^{-1}. The expansion of the lake area was considered to be at the rate of 26 $\times10^5$ m^2a^{-1}, although the average depth decreased by 54 cm a^{-1}.

If the terminal moraine and dead ice portion, which are damming the lake water, were to completely burst, a flood volume of 21×10^6 m^3 (up to 30 m depth), would be generated. The estimated flood volume in 2002 was 40% larger than in 1992.

1. INTRODUCTION

Several moraine-dammed glacial lakes have recently developed in the Great Himalayan countries such as Nepal, Bhutan, India and China. Some glacial lakes have generated severe floods (LIGG / WECS / NEA, 1988), which are called Glacial Lake Outburst Floods (GLOF). Fourteen GLOFs have occurred since 1964 in the Nepal Himalayas (Yamada, 1998), and at least 5 GLOFs were reported in the Bhutan Himalayas (Iwata et al., 2002). Mitigation and prevention of GLOF hazards is one of the urgent issues facing water resource development in the Himalayas today.

Moraine-dammed glacial lakes have appeared on the ablation area covered with thick debris in a large valley glacier in the Himalayas. These lakes were surrounded by a huge lateral and terminal moraine 10 to 100 m in height. The moraine was formed during the Little Ice Age from the 16th to the 19th century. Since the moraine sometimes contains glacier ice, it easily collapses, and the released lake water generates severe flooding accompanied with mudflow.

Moraine-dammed lakes are still expanding, and new lakes are also being formed in the Himalayas even now. The expansion rate of a lake area is relatively easy to estimate using aerial photos, maps, satellite imagery and general surveys (Yamada, 1998; Ageta et al., 2000). On the other hand, the expansion rate of the lake volume is a significant way to estimate GLOF damage. However, this expansion rate has not yet been obtained because of the rather laborious depth measurements involved.

Imja Glacial Lake in the Khumbu region of eastern Nepal is one of the potentially dangerous lakes in the Nepal Himalayas. We attempted to obtain the volume expansion rate by bathymetric surveys conducted 2 times in 10 years; in 1992 (Yamada and Sharma, 1993) and 2002. This paper describes the increasing rate of the stored water volume and area in Imja Glacier Lake over 10 years.

2. LOCATION

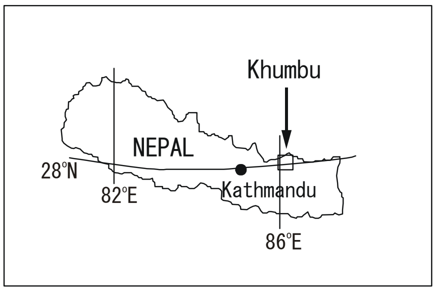

Figure 1 Location of Khumbu area in Nepal.

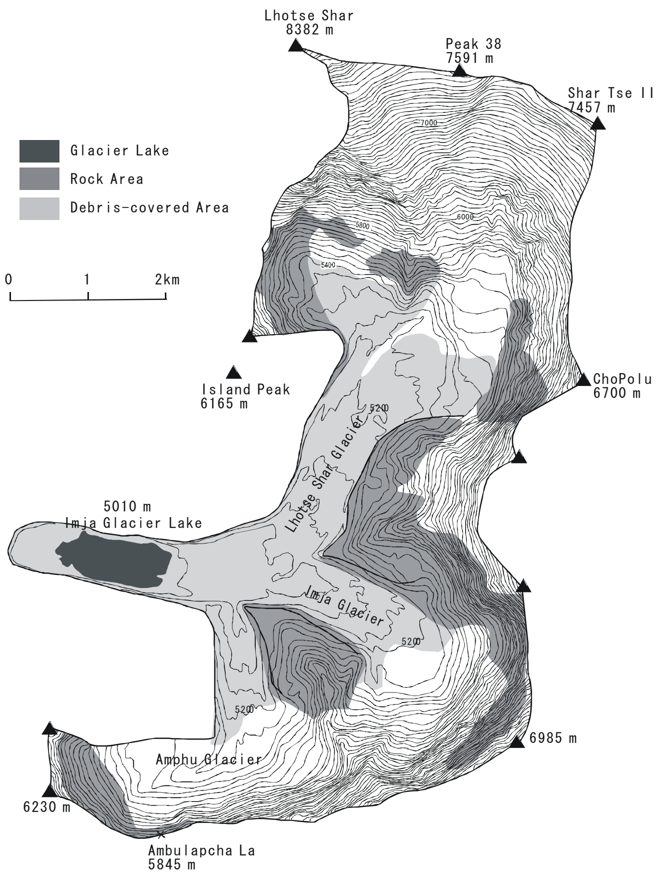

Figure 2 Location of Imja Glacier Lake and its drainage area.

Imja Glacial Lake is located at the termini of the Imja Glacier (27°59’N, 86°56’E) in the Khumbu region of eastern Nepal at an altitude of 5010 m a.s.l. as shown in Fig. 1. Imja Glacier has a branch glacier, Lhotse Shar Glacier, as shown in Fig. 2. Amphu Glacier is also located in the same watershed (Fig. 2), but the glacier tongue does not flow into the Imja Glacier and has been separated from the Imja Glacier now due to glacier retreat.

In the 1950’s Imja Glacial Lake had a few small supra-glacial ponds near the terminal moraine. However, now the lake makes direct contact with the lateral moraines on both sides, the cliff-shaped glacier terminus in the up-lake side and debris-covered dead ice at the downstream side. The lake water was dammed by terminal moraine and dead ice portion, which was left to melt under a layer of thick debris.

3. OBSERVATION METHODS

Observation at Imja Glacial Lake was carried out in early April of 1992 and 2002 during the ice-covered period. The depth measurement was made by a tape measure through boreholes made with a fisherman's drill at 80 points dispersed uniformly on the lake in 2002, and at 61 points in 1992. The position of each point was basically determined by compass and tape measure in both years. Depth measurement points only along a longitudinal line were surveyed by GPS in 2002.

It was too dangerous to install mirrors along the shoreline, because the moraine and top edge of the ice cliff at the terminus of the glacier have a steep slope and rockfalls often occurred. The shoreline of the lake was measured both times by a compass and a laser distance meter from each depth measurement point near the shoreline. The accuracy of the distance meter was ±1 m.

4. RESULTS

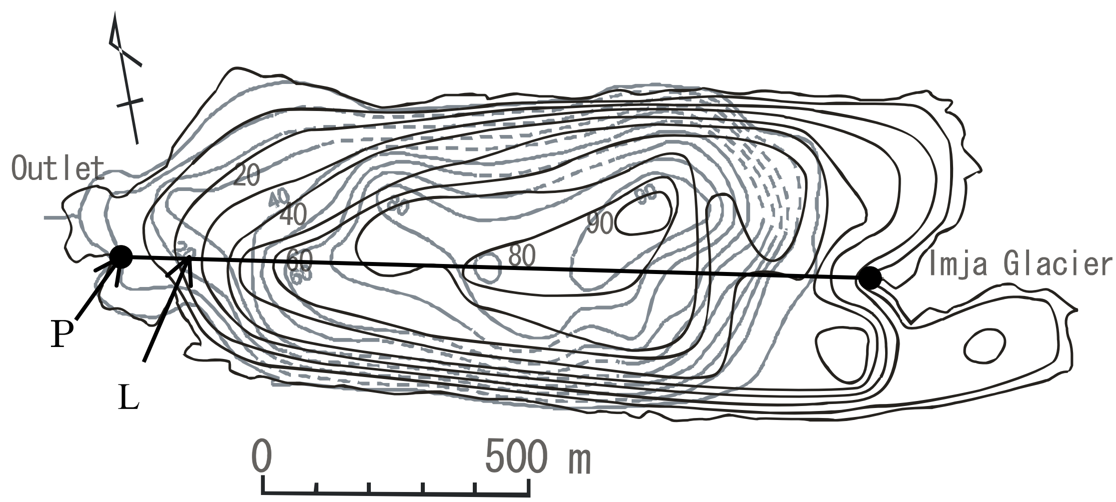

Figure 3 Bathymetric maps of 1992 and 2002 are shown by gray and solid lines, respectively. Dotted gray depth line is uncertain, since there were no depth data in 1992. Site P is the location in 1992 assumed to be the same as in 2002. The depth profile along line L is shown in Fig. 4.

Satellite images of Imja Glacial Lake in 1992 and 2002 indicate that the shoreline near the outlet did not change much over the 10 years. Therefore, bathymetric maps obtained in 1992 and 2002 are superimposed, assuming that the site P in 1992 was assumed to be the same with that in 2002 in Fig. 3. The area has expanded in the upstream direction due to the retreat of the glacier terminus caused by calving.

Figure 4 shows the longitudinal depth profile along line L (shown in Fig. 3) based on raw data in 1992 and 2002, by assuming that the water level in 1992 was equal to that in 2002, since the relative height between the water level and the river bed in 2002 was about 30 m, which is equal to that in 1994 from Watanabe et al. (1995, 1994). The area of expansion was concentrated in front of the glacier terminus.

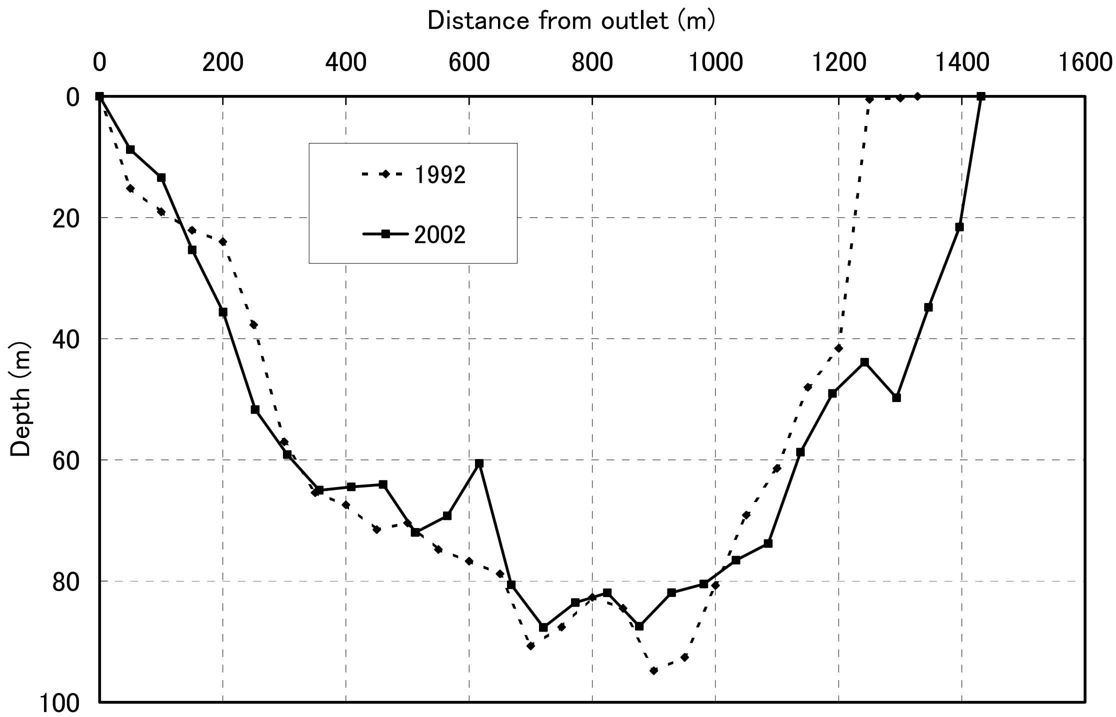

Figure 4 Depth profile along the longitudinal line 'L' shown in Fig. 3.

Table 1 Area, stored water and average depth data on Imja Glacier Lake in 1992 and 2002.

	Unit	1992 *	2002
Area	km^2	0.60	0.86
Stored water	$\times 10^6\ m^3$	28.0	35.8
Average depth	m	47.0	41.6

*: Yamada (1998)

A summary of the respective volume, area and average depth in 1992 and in 2002 is shown in Table 1. The surface area of the glacier lake in 2002 has become 40% larger than in 1992. The stored water volume in 2002 was 28% larger than in 1992.

The relative height of the water level of the glacial lake and the level of the river bed was approximately 30

m. If the terminal moraine and dead ice portion damming the lake water completely collapse, the lake water above 30 m depth will drain away, while the lake water more than 60 m in depth will remain. The lake water volume above 30 m depth in 1992 and 2002 was 15×10^6 m^3 and 21×10^6 m^3, respectively. Therefore, the estimated total flood volume in 2002 when the dam (the terminal moraine and the dead ice portion) broke was more than 40% greater than in 1992.

5. CONCLUDING REMARKS

It was clarified that the volume of the lake in 2002 was approximately 30% larger than in 1992 and that the expanded portion of the glacial lake was concentrated at the glacier front, and that the glacial lake is expanding mainly by calving.

The calving process is different depending on the condition of glacier ice, whether the glacier ice is floating in the lake water or grounding on the base rock (Warrens et al., 2001). In future studies, the ice cliff height and lake depth at the front of the glacier should be observed, in order to judge the condition of the glacier terminus.

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