Glacial lakes and its expansion in the north-central Bhutan and Kulha Kangri massif, Eastern Himalaya

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A great number of the glacial lakes have appeared in many mountain areas of the world during the last half-century due to global warming. Severe floods have been caused by frequent outbursts from the glacial lakes. These glacial lake outburst floods (GLOF) have also occurred in the Himalayan mountains (e.g., Vuichard and Zimmermann 1987, Xu and Feng 1994), including Bhutan Himalaya. The last outburst flood in Bhutan, which originated from Lugge Glacial Lake in October 1994, caused damage to property along the river with the loss of more than 20 lives (Watanabe and Rothacher 1996). Hence, investigation of the glacial lakes is necessary for disaster prevention in Bhutan and the downstream region. Geological Survey of Bhutan (1999) and Mool et al. (2001) made the inventory of the glaciers and glacial lakes in Bhutan. Ageta et al. (2000) and Komori et al. (2003) obtained the expansion records of the lakes in Bhutan. However, much remains to be established about the spatial and temporal variation of glacial lakes not only in Bhutan but also the other Himalayan mountains. The present study revealed the current condition of glacial lakes and its secular variations during the last 45 years.

Study area and method

The study area is focused in the north-central Bhutan and Kulha Kangri massif, border region of Tibet which are the headwater of Chamkhar Chhu (river) and Kuri Chhu (lat. 27º59'-28º24' N, long. 90º28'-91º10' E), the upper streams of the Manas river system. Distribution and development history of the lakes is revealed from detail tracing by the image-editing program (Deneba Canvas 9), using digitized two CORONA satellite imagery (about 10 m digitized resolution, taken in 1967 and 1968), two Landsat satellite imagery (normal resolution of 30 m, taken in 1990 and 2000) and three SPOT satellite imagery (nominal resolution of 10 - 20 m, taken in 1991, 1993 and 2001). The Indian toposheets (1:50,000 in scale, based on aerial photographs taken in 1956 and 1958) and the Soviet toposheets (1:200,000 in scale, based on aerial photographs taken from 1972 to 1974) were used for geometric correction. The field investigation in Chamkhar Chhu was carried out in late September 2002, with the cooperation of the Geological Survey of Bhutan.

Results and discussion

More than twenty glacial lakes, located on the surface or front of the glacier in the headwater of Chamkhar Chhu and Kuri Chhu are recognized. In particular, detail observation was carried out for 19 potentially hazardous lakes which are large and expanding water area, and showing dangerous situation. The observation provided important and previously unknown information. The serial number of hazardous lakes in Chamkhar Chhu and Kuri Chhu basin were given as CGL-1, 2, 3, and KGL-1, 2, 3, tentatively. The summarized features of these lakes as follows:

(1) Lake area: Maximum area of hazardous lakes is 1.70 km^2 (KGL-13, **Figure 1**). Besides, three lakes area are over 1 km^2.

(2) Expansion rate: **Figure 2** showing the expansion rate of the lake area in the southern and northern side of the Himalaya. The largest expanding lake in Chamkhar Chhu and Kuri Chhu basin shows highly expansion rates of 0.027 km^2/y (CGL-6, Chamkhar glacial lake) and 0.025 km^2/y (KGL-13), respectively.

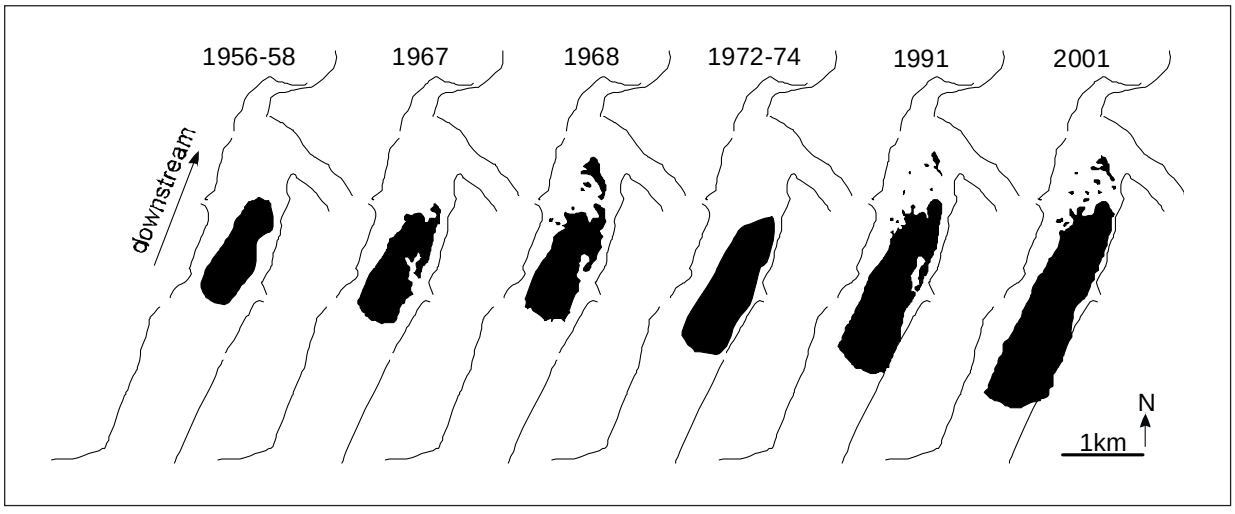

Figure 1. Area variation of KGL-13 from 1956-58 to 2001. Outer solid line is the outline of the glacier

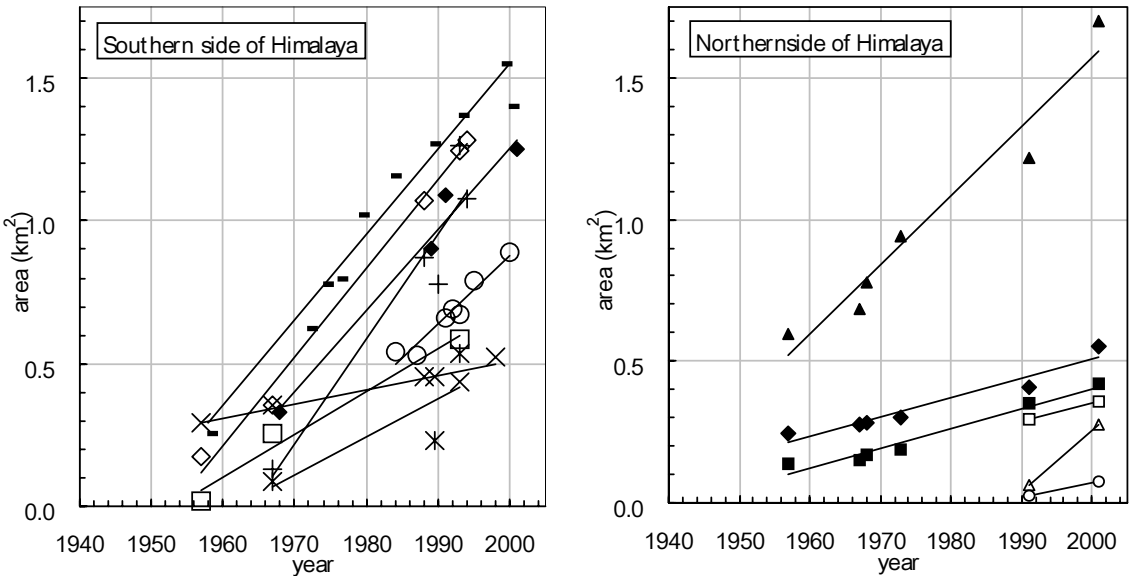

FIGURE 2. Expansion rate of the glacier

The highest rate of 0.037 km^2/y are calculate from Lugge glacial lake. On the other hand, some small lakes and supraglacial ponds show low expansion rate of up to 1 km^2/y. The expansion rates of the northern side are relatively slower than the other side. Some expansion rate of latter period is higher than early period.

(3) Topographical feature: These lakes are classified as the moraine dammed proglacial lake and supraglacial lake (or ponds). Most expansion has advanced at the upper end of the lakes which is contact part between the water area and ice cliff of glacial ice.

Extrapolation of the expansion rate indicates that the initial water area of the southern side of the Himalaya appeared in the 1950s to early 1960s. On the contrary, the emergent year of lakes at the northern side of the Himalaya vary about from 1940s to early 1990s. The differentiation of the expansion rate and emergent year are caused by differences of meteorological and topographical condition at both side of Himalaya mountains. In addition, increasing the expansion rate and appearance the initial water area at the northern side (KGL-11 and KGL-10) in the late 1980s to early 1990s suggests that the enhanced global warming closely affected the glacial lake forming. In the presentation, we will incidentally exhibit the some types of lake expansion and one of the evidence of GLOF occurrence before 1967.

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FIGURE 2. Expansion rate of the glacier

Right: in the southern side of the Himalaya. -:Tsho Rolpa, ○ : Imja lake, ◇ : Raphsthreng, + : Lugge, * : Thorthomi, □ : Wackey, × : Mouzom, ● : Chubda
Left: in the northern side of the Himalaya. ▲ : KGL-13, ◆ : KGL-9, ■ : KGL-12, △ : KGL-11, ○ : KGL-10, □ :KGL-12

The plots of Fig 2-b and Chubda glacial lake are based on this study. Tsho Rolpa and Imja were reffered form Yamada et al.(1998) and Yabuki (2003), respectively. The othe data are digitized and measured from the figures in Ageta et al. (2000).