

# EXPANSION OF MORaine-DAMMED GLACIAL LAKE IN THE CENTRAL HIMALAYAS FROM 1977 TO 2009

Lizong Wu<sup>a</sup>, Xin Li<sup>a</sup>, P. K. Mool<sup>b</sup>, Sharad Joshi<sup>b</sup>, Shiyin Liu<sup>a</sup>

a. Cold and Arid Regions Environmental and Engineering Research Institute, Chinese Academic of Science

b. International Centre for Integrated Mountain Development

## ABSTRACT

The glacial lakes from 1977 to 2009 in the Nepal–China border region were investigated using satellite imagery. 247 ice-contact or ice-proximal glacial lakes with total area of 126.3km<sup>2</sup> in the study area were identified in 2009. The expansion rate of growing lakes are approximately <70m/year in length and 0.12 km<sup>2</sup>/year in area since 1977, respectively. The glacial lake growth rate keeps increase from 1977. The expansion rate of growing lake on southern side is greater than that on northern side.

**Keywords—Glacial lake, Himalayas, Growth rate**

## 1. INTRODUCTION

As glaciers have retreated and thinned, numbers of glacial lakes have recently appeared and expanded in and around alpine glaciers. Glacial lake outburst floods (GLOFs) are extremely hazardous and have frequently occurred in high mountain areas. The Himalaya is one of the most heavily glaciated area in the world outside the polar region. Glacial lake outburst floods (GLOFs) pose significant threats to people and infrastructure in Himalaya[1]. In the last half century, several glacial lakes have rapidly developed and burst in the Hindu Kush-Himalayas, some of which have caused considerable damage across international borders [2]. Glaciological and hydrological studies showed that the

water bodies of glacial lakes have an effect on shrinkage of the adjacent glacier [3,4]. And the glacial lake growth rate is also an important criteria used to identify “potentially dangerous lakes” [5,6]. However, studies of lake formation processes and regional differences in lake development based on long-term and extensive investigations are lacking. Therefore, it is thus important to understand the process of glacial lake development using satellite images.

## 2. THE STUDY AREA

The study area is the trans-border region between Nepal, Tibet Autonomous Region of China and the Sikkim of India (27-30.5°N, 81-89°E). This area encompasses the upper catchment of the Brahmaputra, Ganges and Indus, as well as inland rivers of southern Tibet. In which, there are a large number of mountain glaciers and moraine-dammed lake, and many GLOF events are reported in this region [2].

## 3. METHOD

Glacial lake distributions and development history were investigated using detailed delineations and measurements of satellite-derived imagery from the following sources: Landsat multispectral scanner (MSS; nominal 90m resolution, observed in December 1977, orthorectified), Landsat thematic mapper (TM;

nominal 30-m resolution, observed in November 1990, orthorectified), Landsat enhanced thematic mapper (ETM; nominal 15–30-m resolution, observed in 2000, orthorectified), and Landsat thematic mapper and enhanced thematic mapper (TM and ETM; nominal 15-30m resolution, observed in 2009, orthorectified). The maximum measurement error of a few thousand square meters in area and several tens of meters in lake length might arise from using multiple imagers [7,8]. Hence, this study just focuses on moraine dammed ice-contact or ice-proximal lakes which are larger than 0.1 km<sup>2</sup> in area.

#### 4. RESULT AND DISSCUSS

##### 4.1 Result

247 ice-contact or ice-proximal glacial lakes with total area of 126.3km<sup>2</sup> in the study area were identified in 2009. There are 131 glacial lakes with total area of 80.5km<sup>2</sup> on the northern side of Himalaya and 116 glacial lakes with 45.7km<sup>2</sup> on the southern side of Himalaya, respectively. Figure 1 has shown the glaciers, the ice-contact or ice-proximal glacial lakes in this study area. The glacial lake and their variation on different side of Himalaya in difference periods have summarized in Table 1. According to the result, two distribution characteristics are found in this region: 1) the average glacial lake area and length on the northern side (0.61km<sup>2</sup> in area, 1438m in length) are usually larger than that on the southern side (0.39km<sup>2</sup> in area, 1161m in length), and 2) the average altitude of glacial lakes on northern side (5321m) is usual more high than these on southern side (5040m).

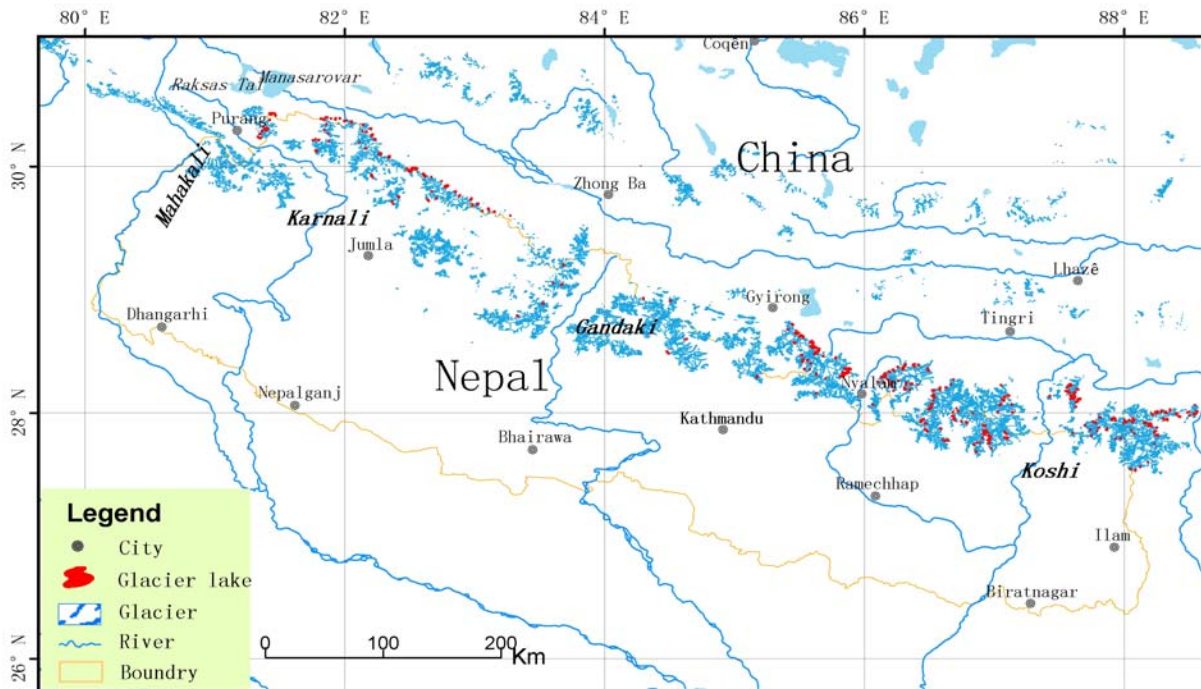


Figure 1 Glaciers and ice-contact or ice-proximal glacial lakes in the Nepal-China-Sikkim border region

Table 1 Summary table of glacial lake variation in difference period in the study area

Period	Glacial lake change	Northern side	Southern side	Total
Before	Total number of glacial lake	42	16	58
1977	Total area of glacial lake(km <sup>2</sup> )	22.95	7.52	30.48
1977-1990	Total number of glacial lake	119	96	215
	Total area of glacial lake(km <sup>2</sup> )	64.47	31.80	96.27
	Total number of stable glacial lake	70	70	140
	Total area of stable glacial lake(km <sup>2</sup> )	33.37	19.10	52.47
	Total number of growing glacial lake	48	26	74
	Total area of growing glacial lake(km <sup>2</sup> )	30.86	12.70	43.56
	Growth rate in area of growing glacial lake(m <sup>2</sup> /year)	0.007	0.010	0.008
	Growth rate in length of growing glacial lake(m/year)	16	24	19
	Total number of shrinking glacial lake	1	0	1
	Total area of shrinking glacial lake(km <sup>2</sup> )	0.24	0	0.24
	Shrink rate in area of growing glacial lake(m <sup>2</sup> /year)	0.016	0	0.016
	Shrink rate in length of growing glacial lake(m/year)	23	0	23
	1990-2000	Total number of glacial lake	129	110
Total area of glacial lake(km <sup>2</sup> )		71.91	39.05	110.96
Total number of stable glacial lake		75	75	150
Total area of stable glacial lake(km <sup>2</sup> )		36.59	21.65	58.24
Total number of growing glacial lake		52	34	86
Total area of growing glacial lake(km <sup>2</sup> )		33.81	16.25	50.06
Growth rate in area of growing glacial lake(m <sup>2</sup> /year)		0.011	0.013	0.012
Growth rate in length of growing glacial lake(m/year)		25	33	28
Total number of shrinking glacial lake		2	1	3
Total area of shrinking glacial lake(km <sup>2</sup> )		1.51	0.26	1.77
Shrink rate in area of growing glacial lake(m <sup>2</sup> /year)		0.006	0.027	0.013
Shrink rate in length of growing glacial lake(m/year)		11	44	22
2000-2009		Total number of glacial lake	131	116
	Total area of glacial lake(km <sup>2</sup> )	80.54	45.71	126.26
	Total number of stable glacial lake	76	78	154
	Total area of stable glacial lake(km <sup>2</sup> )	38.24	23.60	61.84
	Total number of growing glacial lake	49	38	87
	Total area of growing glacial lake(km <sup>2</sup> )	34.50	22.11	56.61
	Growth rate in area of growing glacial lake(m <sup>2</sup> /year)	0.013	0.016	0.015
	Growth rate in length of growing glacial lake(m/year)	29	31	30
	Total number of shrinking glacial lake	6	0	6
	Total area of shrinking glacial lake(km <sup>2</sup> )	3.22	0	3.22
	Shrink rate in area of growing glacial lake(m <sup>2</sup> /year)	0.005	0	0.005
	Shrink rate in length of growing glacial lake(m/year)	11		11

#### 4.2 Expanding of glacial lake

Not all glacial lakes which are greater than 0.1km<sup>2</sup> in area have grown obviously since 1977. Approximately 140 lakes never grew after 1977, and 14 moraine dammed lakes have reach stable state from increase state since 1977. 6 glacial lakes have shrink or switched to shrink state since 1977. Expansion rate of

growing lakes are approximately <70m/year in length and 0.12 km<sup>2</sup>/year in area since 1977, respectively. The glacial lake growth rate also keeps increase on both side of Himalaya since 1977. The average growth rate has increased from 19 m/year to 30 m/year in length since 1977. However, the expanding of glacial lakes in the study area are also shown obviously regional difference: 1) The number of growing lakes on

northern side is larger than that on southern side, and 2) The growth rate on northern side is also larger than that on southern side. The average growth rate on northern side is approximately 0.009 km<sup>2</sup>/year in area and 21m/year in length. In contrast, growth rate on southern side is approximately 0.013 km<sup>2</sup>/year and 25m/year.

## 5. CONCLUSION

1) Glacial lake inventory are essential method to investigate glacial lakes in large area and provide basic data for glacial lake risk assessment. However, types of errors are caused by resolution of satellite images, and snow cover, clouds and shadows on the images. It's difficult to analyze the glacial lake variation through the total area change based on repeated glacial lake inventories. To reveal glacial lake expanding, analysis on glacial lake which greater than 0.1km<sup>2</sup> in area is better than that on the result of repeated glacial lake inventory.

2) In central Himalaya, expansion rate of growing lakes are approximately <70m/year in length and 0.12 km<sup>2</sup>/year in area since 1977, respectively. The glacial lake growth rate also keeps increase from 1977.

3) The glacial lakes and their expanding show obviously regional difference. The total number and average area of glacial lake on northern side of Himalaya are larger than these on southern side. However, the expansion rate of growing lake on southern side is greater than that on northern side.

## 6. REFERENCES

[1] S. D. Richardson and J. M. Reynolds, "An overview of glacial hazards in the Himalayas," *Quaternary International*, vol. 65/66, pp. 31-47, 2000.

[2] J. D. Ives, R. B. Shrestha and P. K. Mool, *Formation of Glacial Lakes in the Hindu Kush-Himalayas and GLOF Risk Assessment*. Kathmandu: ICIMOD, 2010.

[3] K. Chikita, J. Jha and T. Yamada, "Sedimentary effects on the expanse of a himalayan supraglacial lake," *Global and Planetary Change*, vol. 28, pp. 23-34, 1999.

[4] A. Sakai, K. Chikita and T. Yamada, "Expansion of a moraine-dammed glacial lake, Tsho Rolpa, in Rolwaling Himal, Nepal Himalaya," *Limnol. Oceanogr.*, vol. 45, pp. 1401-1408, 2000.

[5] J. M. Reynolds, "Photographic feature: Glacial hazard assessment at Tsho Rolpa, Rolwaling, Central Nepal," *Quarterly Journal of Engineering Geology*, vol. 32, pp. 209 - 214, 1999.

[6] P. K. Mool, S. R. Bajracharya and S. P. Joshi, *Inventory of glaciers, glacial lakes, and glacial lake outburst flood monitoring and early warning system in the Hindu Kush-Himalayan Region, Nepal*. Kathmandu, Nepal: ICIMOD, 2001.

[7] J. Komori, "Recent expansions of glacial lakes in the Bhutan Himalayas," *Quaternary International*, vol. 184, pp. 177-186, 2008.

[8] F. Paul, C. Huggel, A. Käab, T. Kellenberger, and M. Maisch, "Comparison of TM-Derived Glacier Areaa with Higher Resolution Data Sets," in *Proceedings of EARSeL-LISSIG-Workshop Observing our Cryosphere from Space Bern, 2002*, pp. 15-21.