Chapter 11
The Potentially Dangerous Glacial Lakes

On the basis of actively retreating glaciers and other criteria, the potentially dangerous glacial lakes were identified using the spatial and attribute database complemented by multi-temporal remote–sensing data sets. Medium- to large-scale aerial photographs are useful for detailed geomorphic studies and for evaluation of the active glaciers and potentially dangerous lakes.

In general, in terms of geomorphological characteristics, glacial lakes can be grouped into three types: glacial erosion lakes, glacial cirque lakes, and moraine-dammed lakes. The former two types of glacial lakes occupy the lowlands or emptying cirques eroded by ancient glaciers. These glacial lakes are more or less located away from present-day glaciers and the downstream banks are usually made of bedrock or covered with a thinner layer of loose sediment. Both of these glacial lakes do not generally pose an outburst danger. On the other hand, the moraine-dammed glacial lakes have the potential for bursting. A standard index to define a lake that is a source of potential danger because of possible bursting does not exist.

Moraine-dammed glacial lakes, which are still in contact or very near to the glaciers, are usually dangerous. In most of the literature/reports, the term 'glacier lake' is used for such lakes, and the term 'glacial lakes' used for glacier erosion lakes and glacier cirque lakes. The present study defines all the lakes formed by the activity of glaciers as 'glacial lakes'. Moraine-dammed glacial lakes are usually dangerous. These glacial lakes were partly formed between present-day glaciers and Little Ice Age moraine. The depositions of Little Ice Age moraines are generally about 300 years old, form high and narrow arch-shaped ridges usually with a height of 20–150m, and often contain dead glacier ice layers beneath them. These end moraines are loose and unstable in nature. The advance and retreat of the glacier affect the hydrology between the present-day glacier and the lake dammed by the moraines. Sudden natural phenomena with a direct effect on a lake, like ice avalanches or rock and lateral moraine material collapsing on a lake, cause moraine breaches with subsequent lake outburst events. Such phenomena have been well known in the past in several cases of moraine-dammed lakes, although the mechanisms at play are not fully understood.

11.1 Criteria for Identification

The criteria for identifying the potentially dangerous glacial lakes are based on field observations, processes and records of past events, geomorphological and geo-technical characteristics of the lake and

surroundings, and other physical conditions. The potentially dangerous lakes were identified based on the condition of lakes, dams, associated mother glaciers, and topographic features around the lakes and glaciers.

Rise in lake water level

In general the lakes which have a volume of more than 0.01 km^3 are found to have past events. A lake which has a larger volume than this is deeper, with a deeper part near the dam (lower part of lake) rather than near the glacier tongue, and has rapid increase in lake water volume is an indication that a lake is potentially dangerous.

Activity of supraglacial lakes

Groups of closely spaced supraglacial lakes of smaller size at glacier tongues merge as time passes and form bigger lakes such as Lugge Tsho Glacial Lake which is associated with many supraglacial lakes in the topographic map of 1968 (Figure 8.5). The successive merging of supraglacial lakes in the Lugge Tsho Glacial Lake has formed a bigger lake as shown in satellite images from different years (Figure 8.5).

Some new lakes of considerable size are also formed at glacier tongues such as the lakes at Raphstreng Glacier.

These activities of supraglacial lakes are indications that the lakes are becoming potentially dangerous.

Position of lakes

The potentially dangerous lakes are generally at the lower part of the ablation area of the glacier near to the end moraine, and the mother glacier should be sufficiently large to create a potentially dangerous lake environment. Regular monitoring needs to be carried out for such lakes with the help of multi-temporal satellite images and aerial photographs.

The valley lakes with an area bigger than 0.1 km^2 and a distance less than 0.5 km from the mother glacier of considerable size are considered to be potentially dangerous. Cirque lakes even smaller than 0.1 km^2 associated (in contact or distance less than 0.5 km) with steep hanging glaciers are considered to be potentially dangerous.

In general, the potentially dangerous status of moraine-dammed lakes can be defined by the conditions of the damming material and the nature of the mother glacier. Even the smaller size steep hanging glacier may pose a danger to the lake.

Dam conditions

The natural conditions of the moraine damming the lake determine the lake stability. Lake stability will be less if the moraine dam has a combination of the following characteristics:

- narrower in the crest area
- no drainage outflow or outlet not well defined
- steeper slope of the moraine walls
- ice cored
- very tall (from toe to crest)
- mass movement or potential mass movement in the inner slope and/or outer slope
- breached and closed in the past and refilled again with water
- seepage flow at moraine walls

A moraine-dammed lake, which has breached and closed subsequently in the past and has refilled again with water, can breach again. Nagma Pokhari Lake in the Tamor Basin in Nepal burst out in 1980. The study of recent aerial photographs and satellite images shows a very quick regaining of lake water

volume. Zhangzangbo Lake in the Poiqu Basin in Tibet (China) burst out in 1964 and again in 1981. Recent satellite images show that the lake has refilled with water and, therefore, could pose danger. Ayaco Lake in the Pumqu Basin in Tibet (China) burst out in 1968, 1969, and 1970 and at present it is refilled again with water and poses danger. Regular monitoring of such lakes is necessary using multi-temporal satellite images.

Condition of associated mother glacier

Generally, the bigger valley glaciers with tongues reaching an elevation below 5,000 masl have well-developed glacial lakes. Even the actively retreating and steep hanging glaciers on the banks of lakes may be a potential cause of danger. The following general characteristics of associated mother glaciers can create danger to moraine-dammed lakes:

- hanging glacier in contact with the lake,
- bigger glacier area,
- fast retreating,
- debris cover at glacier tongue area,
- steep gradient at glacier tongue area,
- presence of crevasses and ponds at glacier tongue area,
- toppling/collapses of glacier masses at the glacier tongue, and
- ice blocks draining to lake.

Physical conditions of surroundings

Besides moraines, mother glaciers, and lake conditions, other physical conditions of the surrounding area as given below may also cause the lake to be potentially dangerous:

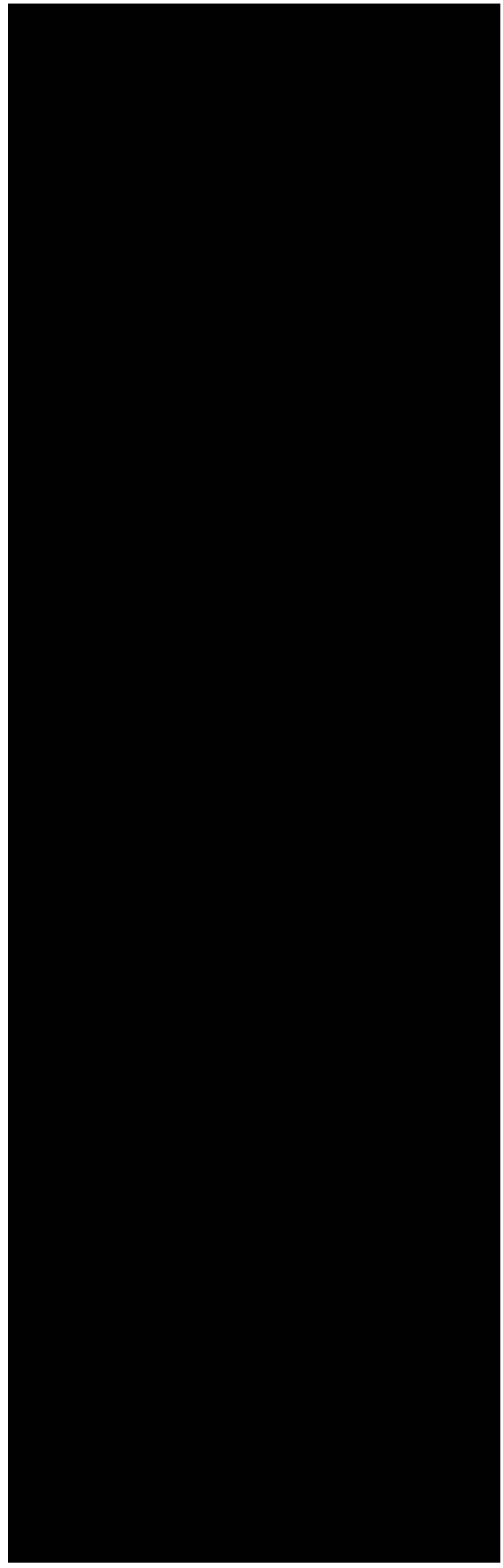
- potential rockfall/slide (mass movements) site around the lake which can fall into the lake suddenly
- snow avalanches of large size around the lake which can fall into the lake suddenly
- neo-tectonic and earthquake activities around or near the lake area
- climatic conditions of successive years being a relatively wet and cold year followed by a hot and wet or hot and arid year
- very recent moraines damming the lake at the tributary glaciers that used to be just a part of a former complex of valley glacier middle moraines as a result of the fast retreat of a complex mother valley glacier (e.g. Lunana area in the Pho Chu Sub-basin)
- sudden advance of a glacier towards the lower tributary or mother glacier having a well-developed lake at its tongue

11.2 Potentially Dangerous Glacial Lakes

Altogether there are 2,674 glacial lakes in Bhutan, among them 562 lakes are associated with glaciers. The lakes are classified according to the distance from the glaciers: at a distance between 500–2,000m, 50–500m, or less than 50m. As the lakes get closer to the glacier and are affected by the different parameters mentioned above, the lakes will be potentially dangerous. Among the glacier associated glacial lakes, 174 lakes are at a distance of less than 50m. The lakes are also classified into different types for the identification of potentially dangerous lakes (Table 11.1). There are different types of lakes associated with glaciers: end moraine-dammed lakes, lateral moraine-dammed lakes, supraglacial lakes, blocked lakes, valley trough lakes, cirque lakes, and erosion lakes. Among these lakes, moraine-dammed lakes and blocked lakes are susceptible to breach out easily due to different phenomena. Supraglacial lakes, when they start merging with one another to form a larger lake and finally change into a moraine-dammed lake, become dangerous.

The study of topographic maps, satellite images, and field information showed that most of the identified potentially dangerous lakes started to form more than 40 years ago.

From the present study, 24 glacial lakes have been identified as potentially dangerous lakes based on the analysis of data using different criteria and the study of topographic maps and satellite images (Figure 11.1 and Table 11.2). Among the identified potentially dangerous lakes, three lakes are in the Chamkhar



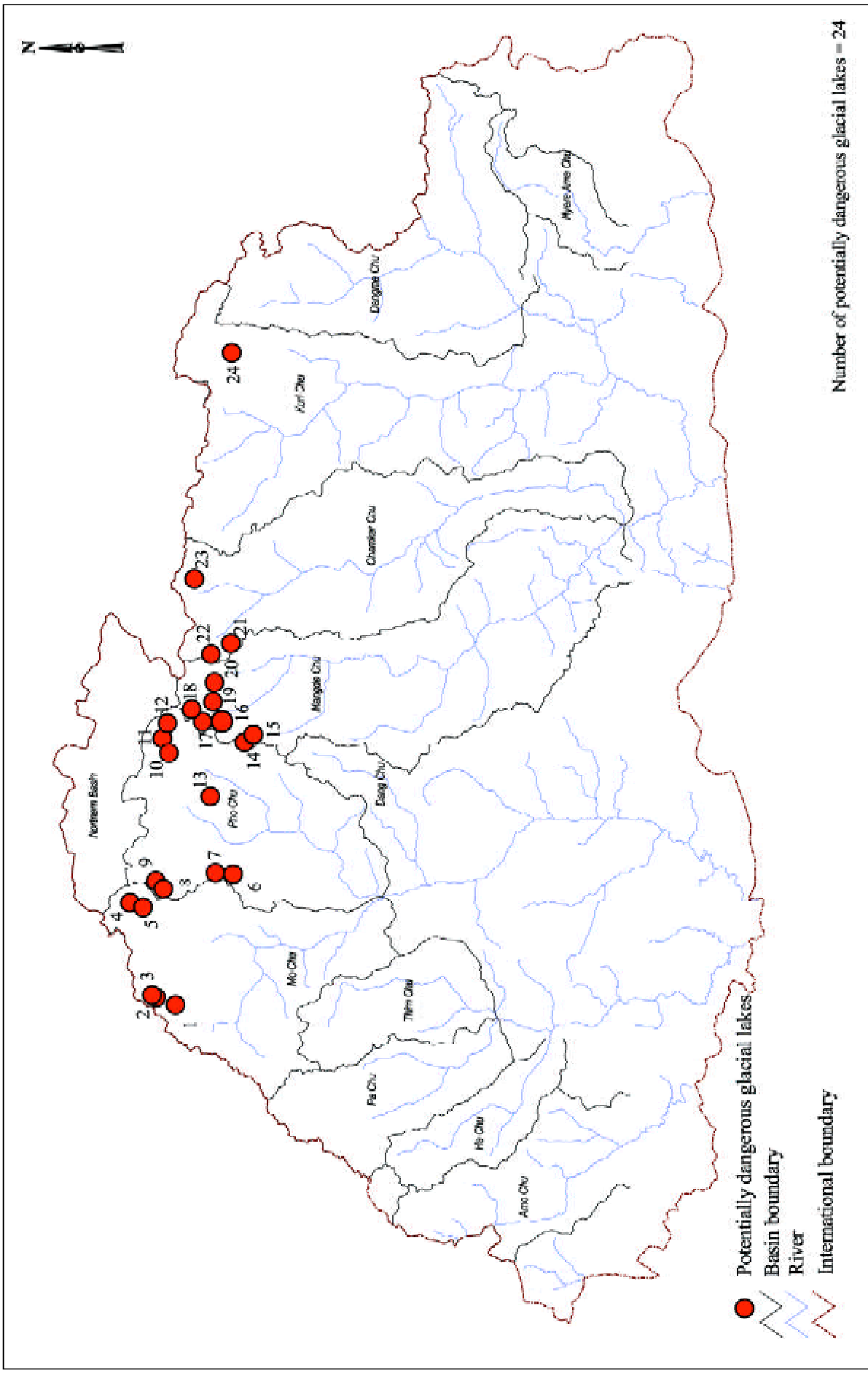


Figure 11.1: Potentially dangerous glacial lakes of Bhutan

Table 11.2: Potentially dangerous glacial lakes in Bhutan							
S. No.	Lake Number	Name Tsho	Latitude	Longitude	Altitude (masl)	Length (m)	Area (m^2)
Mo Chu Sub-basin							
1	Mo_gl 200	Kab	28° 04' 00.00	89° 35' 05.50	4280	285	52 090.11
2	Mo_gl 201		28° 06' 15.60	89° 36' 55.60	4080	325	30 863.71
3	Mo_gl 202		28° 07' 44.40	89° 36' 31.60	4380	325	34 287.76
4	Mo_gl 234	Setang Burgi	28° 10' 06.00	89° 51' 21.10	4480	795	232 774.52
5	Mo_gl 235		28° 08' 35.40	89° 50' 43.00	4960	565	150 131.36
Pho Chu Sub-basin							
6	Pho_gl 84		27° 56' 48.53	89° 55' 14.03	5040	660	214 078.18
7	Pho_gl 148		27° 58' 09.42	89° 56' 16.69	4880	1285	454 510.02
8	Pho_gl 163		28° 06' 06.43	89° 54' 11.83	4280	1200	369 572.13
9	Pho_gl 164	Tarina	28° 06' 37.22	89° 54' 37.81	4320	1095	280 550.42
10	Pho_gl 209	Raphstreng	28° 06' 43.56	90° 14' 03.65	4360	550	145 948.56
11	Pho_gl 210	Lugge	28° 05' 00.34	90° 18' 28.58	4600	1980	769 799.72
12	Pho_gl 211		28° 05' 40.45	90° 19' 11.95	4710	650	141 975.78
13	Pho_gl 313		27° 59' 58.72	90° 07' 18.86	5030	205	222 134.80
Mangde Chu Sub-basin							
14	Mang_gl 99		27° 54' 22.13	90° 16' 45.88	4960	605	192 607.29
15	Mang_gl 106		27° 53' 19.45	90° 17' 33.94	5040	1480	868 294.42
16	Mang_gl 270		27° 58' 09.32	90° 20' 06.98	5280	850	239 778.31
17	Mang_gl 285		28° 00' 20.90	90° 19' 50.77	5390	795	341 412.93
18	Mang_gl 307		28° 02' 21.01	90° 21' 58.87	5240	1800	767 429.06
19	Mang_gl 310		27° 58' 49.87	90° 23' 05.53	5200	575	200 746.06
20	Mang_gl 385		27° 58' 58.53	90° 26' 21.90	5086	535	466 125.34
Chamkar Chu Sub-basin							
21	Cham_gl 198		27° 56' 22.27	90° 32' 15.91	5046	1495	624 669.81
22	Cham_gl 232		27° 59' 11.33	90° 30' 31.42	5200	565	205 146.23
23	Cham_gl 383		28° 01' 25.91	90° 42' 31.77	4840	2645	103 5131.5
Kuri Chu Sub-basin							
24	Kuri_gl 172		27° 55' 47.56	91°18' 08.77		850	161 706.43

Chu Basin, one is in the Kuri Chu Basin, seven are in the Mangde Chu Basin, five are in the Mo Chu Basin, and eight are in the Pho Chu Basin. The Amo Chu, Ha Chu, Dang Chu, and Nyere Ama Chu Basins do not contain potentially dangerous lakes.

The potentially dangerous lakes of the Chamkhar Chu Basin are Cham_gl 198, Cham_gl 232, and Cham_gl 283. The first two lakes are located above 5,000 masl and the last one is below 5,000 masl. The lake areas occupied by Cham_gl 198 and Cham_gl 383 are 0.6 and 1.03 sq.km respectively.

There is only one potentially dangerous lake in the Kuri Chu Sub-basin, on the basis of morphology and position of the lake. The area occupied by the lake is about 0.162 sq.km, but the depth is unknown, as it was not studied. If the average depth of the lake is around 10m, the volume of water will exceed by 1.6 million m^3. Lakes of this type have had GLOF events in the past with the hazard immediately downstream of the breached lake.

Seven glacial lakes are identified as potentially dangerous lakes in the Mangde Chu Sub-basin: Mangd_gl 99, Mangd_gl 106, Mangd_gl 270, Mangd_gl 285, Mangd_gl 307, Mangd_gl 310, and Mangd_gl 385. Mangd_gl 106 and Mangd_gl 307 have an area greater than 0.7 sq.km.

There are five potentially dangerous glacial lakes in the Mo Chu Sub-basin: Mo_gl 200, Mo_gl 201, Mo_gl 202, Mo_gl 234, and Mo_gl 235. The lakes are identified as potentially dangerous on the basis of morphology and position of the lake with respect to the associated glacier. The lake areas of the identified potential dangerous lakes do not exceed 0.25 sq.km.

The potentially dangerous lakes identified in the Pho Chu Sub-basin are Pho_gl 84, Pho_gl 148, Pho_gl 163, Pho_gl 164, Pho_gl 209, Pho_gl 210, Pho_gl 211, and Pho_gl 213. Among them Pho_gl 210 (Lugge Tsho) has had GLOF events in the past, and there are several GLOF events reported from Lunana region but the relevant lakes are unidentified.

Raphshtering Tsho in the Pho_Chu Sub-basin is very well known among layman and researchers. Mitigation measures have been applied on a phase-wise basis to prevent GLOF hazards along the downstream valley.