

Chapter 7

The Inventory of Glaciers

7.1 BRIEF DESCRIPTION OF GLACIER INVENTORY

The inventory of glaciers has been based on topographic maps and satellite images. As not all topographic maps are available for Bhutan and most of the topographic maps of the glaciated region are poor quality photocopies, for the identification, classification, and determination of stages of glaciers, different types of satellite images were vigorously studied. The spatial inventory is based entirely on topographic maps on a scale of 1: 50,000 published in the 1950s to 1970s by the Survey of India and the prints of the land observation satellite (LANDSAT) thematic mapper (TM) images on a scale equivalent to the topographic maps. All the projection parameters of the topographic maps are incorporated in the images to make the prints compatible with the topographic maps.

For the inventory of glaciers, the area is divided into basins and further sub-divided into sub-basins. The aerial extension of the glaciers is found with the help of geographic information systems (GIS). To estimate the ice reserves, it is an utmost necessity to have the mean thickness of the glaciers. Since the mean glacier thickness data are not available, this is estimated from the equation developed for the Tianshan Mountains (Cahohai Liu and Liangfu 1986)

$$H = -11.32 + 53.21F^{0.3}$$

where H = mean ice thickness (m) and F = area of glacier (km^2)

The ice reserves were estimated by multiplying the mean thickness by the area of the glacier.

7.2 TYPES OF GLACIER

The classification of glaciers is adopted from the morphological classification of glaciers by the World Glacier Monitoring Service (WGMS) (Muller et al. 1977). Details of the classification are mentioned in Chapter 4. The classified glaciers are divided into different types, combining Digit 1 of 'primary classification' and Digit 2 of 'form'. Generally, six types of glacier are observed in the Bhutan Himalayas—mountain glaciers, valley glaciers, cirque glaciers, niche glaciers, ice caps, and ice aprons. Mountain glaciers are dominant in quantity and the profile shows a hanging nature. Other glaciers, except

for valley glaciers, generally fall into the category of mountain glaciers but the thickness of ice is comparatively low. The number of valley glaciers is comparatively low but the corresponding areas and ice reserves are higher than those of mountain glaciers. The area and ice reserves of the valley glaciers are generally large owing to the fact that the ice thickness increases with increase in the area of the glacier.

Mountain glaciers are uncertain or miscellaneous, compound basins, compound basin, or simple basin in the form of a hanging glacier. The major source of nourishment is snow and/or drift snow. Ice caps, cirque glaciers, niche glaciers, and ice aprons are other types of hanging mountain glaciers, but they are considered to be a different type due to their significance in size, shape, form, and ice thickness. The most significant valley type glaciers are fewer in number and characterised by compound basins, compound basin, and simple basin. They are mainly nourished by snow and drift snow at the headwater and by snow and ice avalanche at the lower valley. The adjoining part of the valley glacier at the headwaters is characteristically a mountain glacier, but due to its continuation into a valley glacier, the whole ice mass will be considered to be a valley glacier. Hence, the area of the valley glacier is higher than that of the mountain glaciers.

The longitudinal profile of the valley glacier from crown to toe shows an even or regular shape. As the headwater is steeper and has a gentle slope in the lower reaches, the profile makes the curve concave upwards. Due to the gentle slope at the lower reaches and the accumulation of debris derived from the headwater, glacial lakes develop in a supra glacial and moraine dammed form. Generally, the stability of glacial lakes is poor and there is always the chance of avalanches from mountain glaciers, which may break the damming material and cause glacial lake outburst floods (GLOFs).

7.3 GENERAL CHARACTERISTICS OF GLACIATION

The occurrence of glaciers has always been linked to climatic conditions. Climate is of fundamental importance to the inception and growth of glaciers. The form of the landscape dictates the threshold conditions for glacier occurrence and determines glacier morphology. In certain climatic conditions for glaciation, glaciers of different shapes and sizes are formed depending on the landscape. Mountain glacier regions are associated with climatic fronts, zones of maximum precipitation.

The general characteristics of glaciation in the Bhutan Himalayas is not well studied. Tshoju Glacier in Lunana Valley had advanced below Tshoju village in the past. It is recognised by the presence of lacustrine deposits in the Tshoju Plains as a result of the damming of the eastern branch of the Pho Chu by Tshoju Glacier.

Ageta and Iwata (1999) reported retreat of the glaciers in the Bhutan Himalayas with the help of satellite images, maps, and survey data from different years. The terminus of Tarina Glacier retreated around 0.7 km (30 to 35m year⁻¹) from 1967 to 1998. Raphstreng Glacier retreated about 0.5 km (35m year⁻¹) during a 14-year interval. Luge Glacier retreated by 16m year⁻¹ from 1988 to 1993. Generally, the termini of the glaciers of the Bhutan Himalayas are retreating at a rate of 30– 40m year⁻¹.

Table 7.1: Levels of glaciation in different valleys of Bhutan		
Glaciation stage	Elevation (levels)	Remarks
Present glaciers	4,200–5,000 masl	
Recent moraines	4,200–4,700 masl	
Thanza stage (Little Ice Age)	4,000–4,200 masl	150 years old (approximately)
Lingshi stage	3,800–3,900 masl	
Wachey stage	3,500–3,600 masl	
Taksaka stage	3,300–3,400 masl	
Older stages	2,600–3,100 masl	

Gansser (1983) reported that the oldest stage of a glacier in Bhutan extends down to 2,900m. It was recognised from the preservation of remnants of the terminal moraine below the landslide debris in Koma Chu Valley south of Sengge Dzong. He has again distinguished the levels of the glaciers in different valleys as shown in Table 7.1.

4.4 GLACIERS OF BHUTAN

The present inventory is based on topographic maps on a scale of 1:50,000 published by the Survey of India in the period from 1950 to 1970. For this work, the six basins of Bhutan, as indicated in Chapter 3, are divided into thirteen sub-basins as given in Table 7.2. As can be seen from the table, there are no glaciers in the Amo Chu and Nyere Ama Chu Basins and the Ha Chu and Dang Chu Sub-basins.

The majority of the glaciers in Bhutan fall into the primary classification of mountain glaciers with simple basins with their major source of recharge being from snow or avalanches with a marked rate of retreat. Glaciers in the Bhutan Himalayas generally occur above the elevation of 4,000 masl. There are 677 glaciers altogether within the territory of Bhutan (Table 7.2 and Figure 7.1). They cover an area of 1,316.71 sq.km with approximately 127.25 km³ of ice reserves. The details of the glacier inventory for all the sub-basins are given in Annex I.

S. No.	Sub-basin	Basin	Glacier number	Area (km ²)	Ice reserve (km ³)
1	Amo Chu	Amo Chu	0	0	0
2	Ha Chu	Wang Chu	0	0	0
3	Pa Chu		21	40.51	3.22
4	Thim Chu		15	8.41	0.33
5	Mo Chu	Puna Tsang Chu	118	169.55	11.34
6	Pho Chu		154	333.56	31.935
7	Dang Chu		0	0	0
8	Mangde Chu	Manas Chu	140	146.69	11.92
9	Chamkar Chu		94	104.10	8.11
10	Kuri Chu		51	87.62	6.48
11	Dangme Chu		25	38.54	2.26
12	Nyere Ama Chu	Nyere Ama Chu	0	0	0
13	Northern Basin	Northern Basin	59	387.73	51.72
	Total		677	1316.71	127.25

Among the glaciated sub-basins,

Thim Chu has the smallest number of glaciers. Only 15 glaciers with an area of 8.41 sq.km and an ice reserve of 0.33 km³ were found in this sub-basin. The Mo Chu, Pho Chu, and Mangde Chu Sub-basins are the biggest sub-basins consisting of 118, 154, and 140 glaciers respectively. The Northern Sub-basin and the Pho Chu Sub-basin cover areas of 387.73 and 333.56 sq.km respectively. Of the total ice reserve in the Bhutan Himalayas, around 66% is held by the Northern Sub-basin and the Pho Chu Sub-basin.

The Pa Chu Sub-basin

The Pa Chu is a sub-basin of the Wang Chu Basin. It has three major tributaries: the Chomolhari Chu, the Halun Chu, and the Thangothang Chu. The latter two originate from Chomolhari and Kang Phu Glaciers respectively.

The aspect of the glaciers is distributed in all directions except in the east. There is one glacier in the north aspect and one in the west. There are five glaciers in the northwest aspect and five in the southeast. In other aspects there are two to four glaciers (Table 7.3).

The Pa Chu Sub-basin has a total of 21 glaciers and covers an area of 40.51 sq.km with ice reserves of 3.22 km³ (Table 7.4). The two largest glaciers in the sub-basin are Pa_gr 8 and Pa_gr 10. Both of them are valley glaciers and have an area coverage of 11.31 and 10.19 sq.km respectively. Glacier Pa_gr 8 is 6.1 km long and its tongue elevation is 4,320 masl. Glacier Pa_gr 10 is 7.74 km long and its tongue elevation is 4,200 masl (Figure 7.2).

Aspect	N	NE	NW	W	S	SE	SW
Number of glacier	1	2	5	1	4	5	3
Area (km ²)	0.20	0.79	1.61	0.24	19.49	17.18	1.00
Area (%)	0.49	1.95	3.97	0.59	48.11	42.41	2.47
Maximum area (km ²)	0.20	0.43	0.62	0.24	10.19	11.31	0.47
Minimum area (km ²)	0.20	0.40	0.20	0.24	0.50	0.30	0.10
Maximum length (m)	510	5497	1106	745	7739	6055	1398
Minimum length (m)	510	1148	725	745	965	1717	802
Highest elevation (masl)	5570	5600	5642	5340	7226	7326	5570
Mean elevation (masl)	5365	5240	5224	5180	5553	5811	5228
Tongue elevation (masl)	5160	4920	4880	5020	4200	4320	4760
Ice reserve (km ³)	0.004	0.023	0.045	0.006	1.663	1.449	0.029

Glacier type	Number		Area				Ice reserve	
	Number	%	km ²	%	of largest glacier	of smallest glacier	km ³	%
Mountain	12	57.14	15.32	37.82	6.79	0.18	0.981	30.48
Ice apron	7	33.33	3.69	9.11	1.85	0.09	0.147	4.57
Valley	2	9.52	21.50	53.07	11.31	10.19	2.091	64.96
Total	21		40.51				3.219	

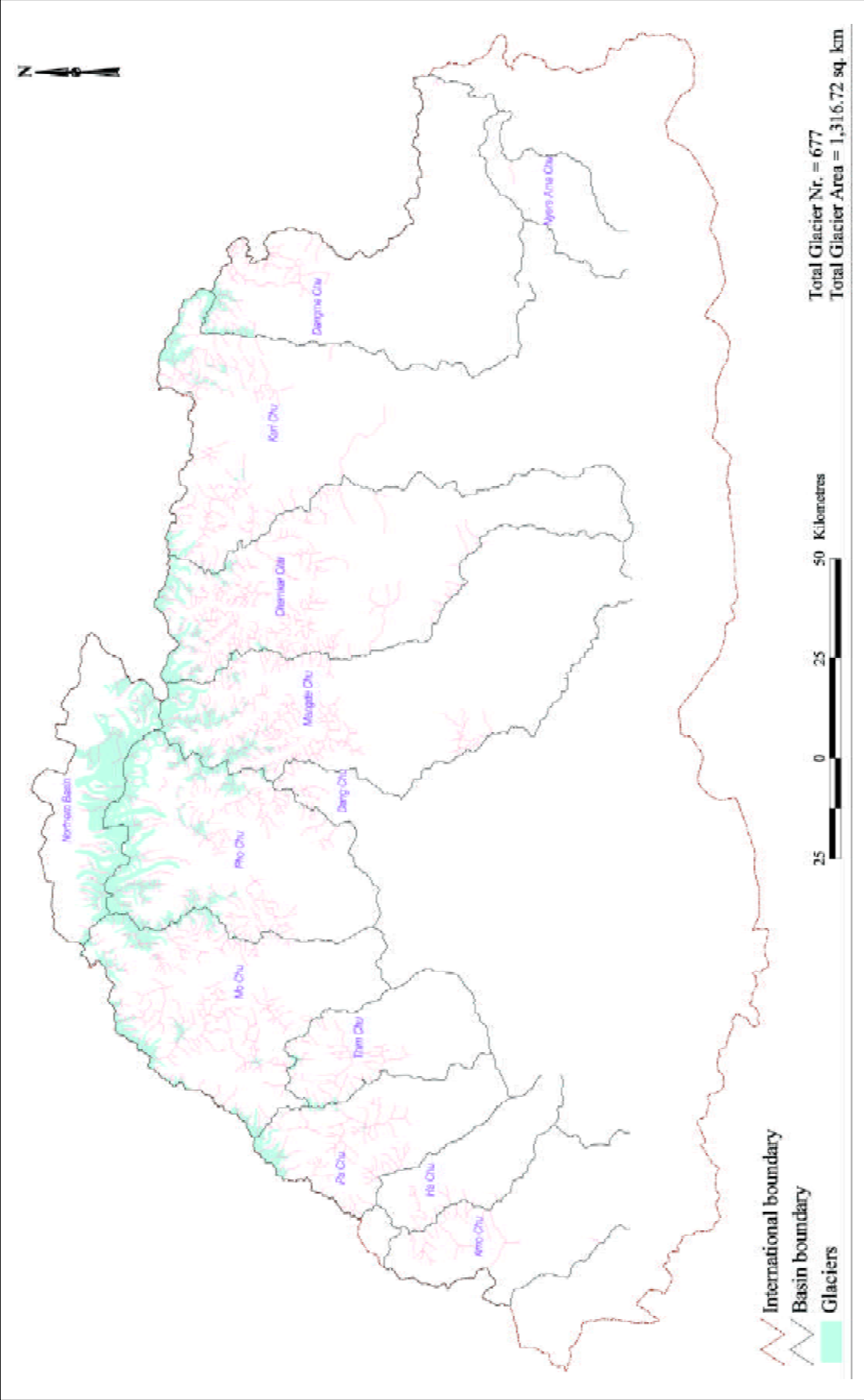


Figure 7.1: Distribution of glaciers in the Bhutan Himalayas

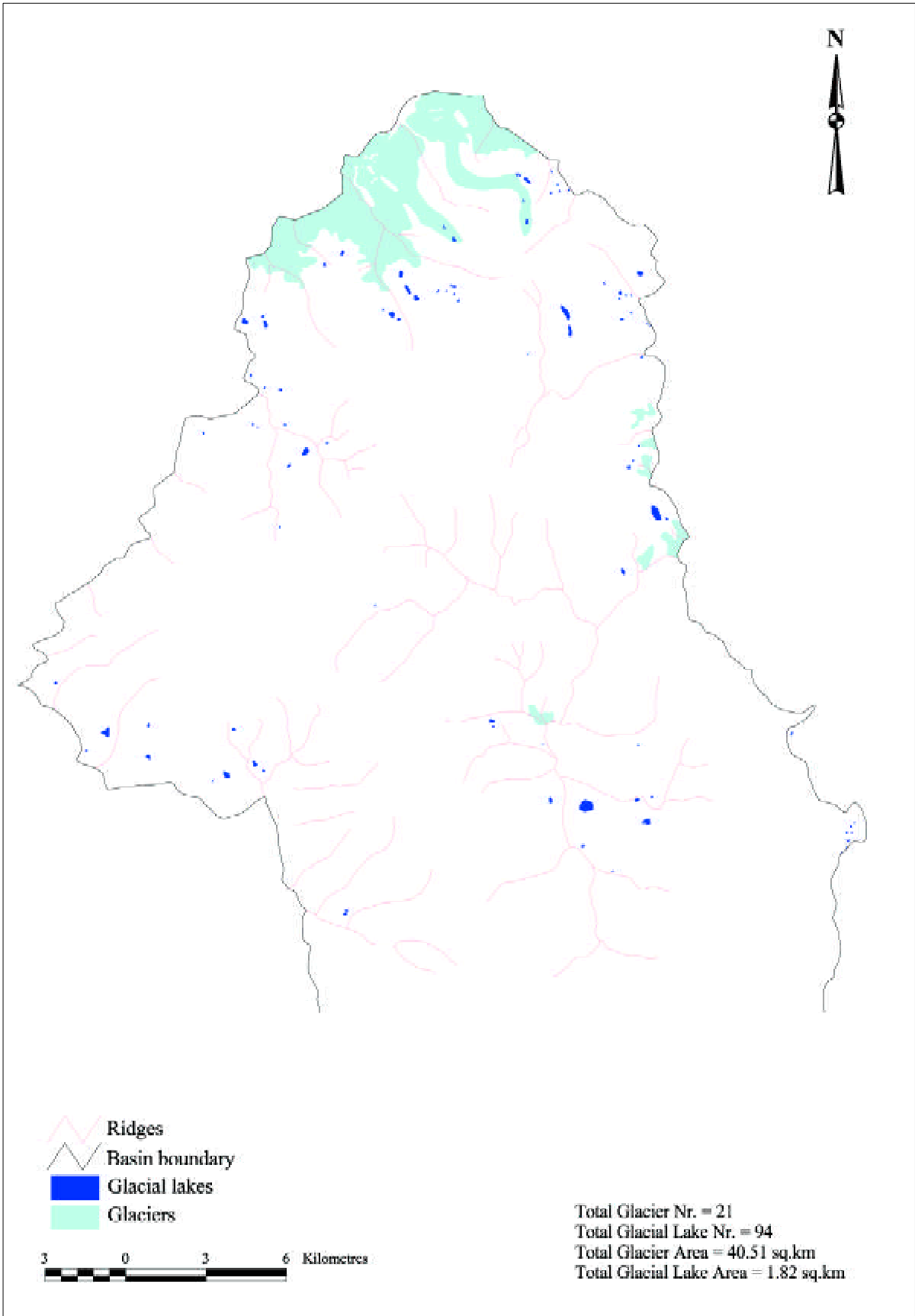


Figure 7.2: Glaciers and glacial lakes of the Pa Chu Sub-basin

There are only three types of glacier in the Pa Chu Sub-basin—mountain, ice apron, and valley. Two valley glaciers cover 53% of the area and 65% of the ice reserve (Table 7.4). The least of the area is covered by ice aprons.

The Thim Chu Sub-basin

The Thim Chu is the easternmost tributary of the Wang Chu. It consists of 15 glaciers with a cumulative area of 8.41 sq.km (Figure 7.3). A northeastern oriented glacier is dominant in the Thim Chu Sub-basin (Table 7.5). The tongue elevation of the northeastern aspect glaciers extends down to 4,840 masl. Generally the tongues of the glaciers for the four other remaining aspects are above 5,000 masl. The

maximum length of the glaciers is 2.25 km and the minimum length is about 0.41 km.

Table 7.5: Summary of glaciers in the Thim Chu Sub-basin with respect to aspect					
Aspect	NE	E	SE	SW	S
Number of glacier	7	2	2	3	1
Area (km²)	3.98	2.04	0.37	1.20	0.46
Area (%)	47.32	28.54	4.40	14.27	5.47
Maximum area (km²)	1.20	1.77	0.33	0.58	0.46
Mean area (km²)	0.57	1.20	0.19	0.40	0.46
Minimum area (km²)	0.10	0.60	0.00	0.20	0.50
Maximum length (m)	1808	2254	660	855	675
Minimum length (m)	415	1202	408	628	675
Highest elevation (masl)	5642	5520	5680	5280	5240
Mean elevation (masl)	5253.43	5235.00	5447.25	5184.67	5200.00
Tongue elevation (masl)	4840	5040	5120	5080	5160
Ice reserve (km³)	0.16	0.11	0.01	0.04	0.01

There are only two types of glacier in this sub-basin—mountain glaciers and ice aprons. The largest glacier covers an area of 5.1 sq.km and the smallest 0.09 sq.km. Glacier tongue elevations range from 4,840 to 5,160 masl. The total ice reserve of all the 15 glaciers is estimated at 0.33 km³ (Table 7.6).

Table 7.6: Distribution of glaciers by type in the Thim Chu Sub-basin.								
Glacier type	Number		Area				Ice reserve	
	Number	%	km²	%	of largest glacier	of smallest glacier	km³	%
Mountain	10	66.67	6.82	81.09	1.77	0.09	0.285	85.59
Ice apron	5	33.33	1.59	18.91	0.58	0.04	0.048	14.41
Total	15		8.41				0.333	

The Mo Chu Sub-basin

The Mo Chu is the westernmost branch of the Puna Tsang Chu. Two branches, one originating from northern Bhutan and the other originating in the west from southeast of Chomolhari Mountain, join to form the Mo Chu. The western branch comprises only 19 glaciers, while the other branch has 99 glaciers. The total area covered by these glaciers is 169.55 sq.km with an ice reserve of 11.34 km³.

The southwestern and southeastern aspect glaciers are dominant (Table 7.7). The largest glacier, Mo_gr 96, has an area of 32.55 sq.km and is located at latitude 28° 5' 34.2" and longitude 89° 50' 27.1" at an altitude of 4,440 masl (tongue elevation of the glacier).

Four types of glacier have been recognised, out of which mountain glaciers are dominant in terms of number. There are 83 mountain glaciers and 12

Table 7.7: Summary of glaciers on the basis of aspect in the Mo Chu Sub-basin									
Aspect	N	NE	NW	E	W	S	SE	SW	
Number of glacier	6	15	13	8	13	12	23	28	
Area (km²)	5.20	11.41	25.38	16.47	21.12	8.94	33.62	47.41	
Area (%)	3.07	6.73	14.97	9.71	12.46	5.27	19.83	27.96	
Maximum area (km²)	1.20	4.81	12.77	8.68	6.55	2.81	8.09	13.22	
Mean area (km²)	0.87	0.76	1.95	2.06	1.62	0.74	1.46	1.63	
Minimum area (km²)	0.40	0.10	0.00	0.10	0.10	0.10	0.10	0.10	
Maximum length (m)	1762	5121	5597	7302	4963	4592	5291	8060	
Minimum length (m)	1174	456	233	450	595	542	512	523	
Highest elevation (masl)	5564	5784	6480	6789	5685	6400	6789	6790	
Mean elevation (masl)	5174	5155	5290	5227	5228	5407	5412	5267	
Tongue elevation (masl)	4760	4680	4520	4120	4800	4400	4120	4080	
Ice reserve (km³)	0.210	0.607	2.059	1.195	1.366	0.414	2.107	3.382	

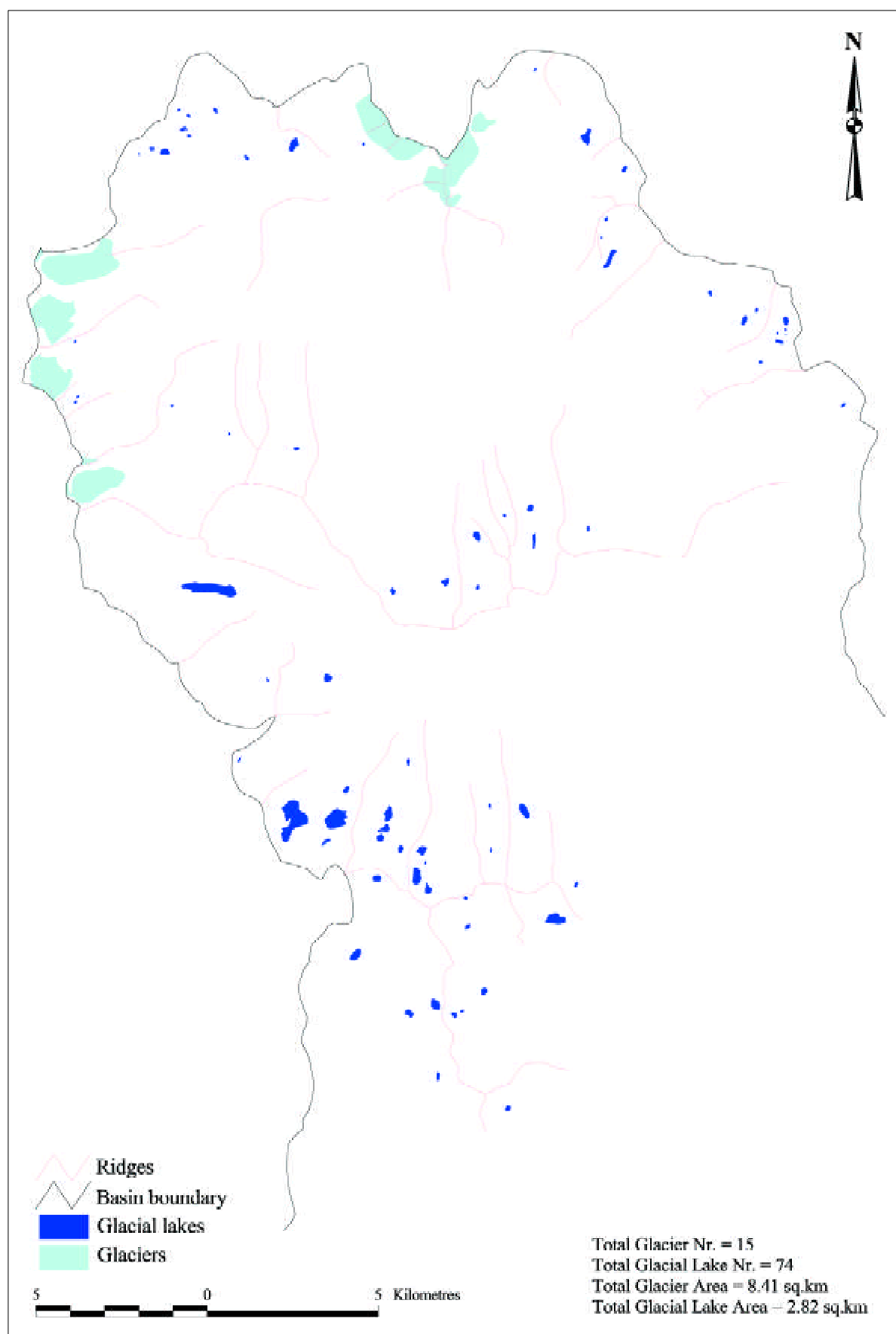


Figure 7.3: Glaciers and glacial lakes of the Thim Chu Sub-basin

valley glaciers (Figure 7.4). Areas occupied by these glaciers are 87.77 and 77.11 sq.km respectively. Out of the total ice reserves in the sub-basin the valley glaciers and mountain glaciers contain 58.84 and 40.09% respectively (Table 7.8).

Table 7.8: Distribution of glaciers by type in the Mo Chu Sub-basin								
Glacier type	Number		Area				Ice reserve	
	Number	%	km ²	%	of largest glacier	of smallest glacier	km ³	%
Mountain	83	70.34	87.77	51.77	6.55	0.07	4.546	40.09
Ice cap	2	1.69	0.08	0.05	0.05	0.03	0.001	0.01
Ice apron	19	16.10	4.41	2.60	0.92	0.10	0.118	1.04
Cirque	2	1.69	0.18	0.11	0.09	0.09	0.002	0.02
Valley	12	10.17	77.11	45.48	13.22	2.60	6.672	58.84
Total	118		169.55				11.339	

The Pho Chu Sub-basin

The Pho Chu is a prominent tributary of the Puna Tsang Chu which is fed by numerous glaciers that exist in the extreme northern part of Bhutan. The river flows through very rugged terrain and deep gorges to join with the Mo Chu near Punakha Dzong. Compared to other parts of the northern region, the largest receding valley glaciers are found in the headwaters of the Pho Chu Sub-basin. This region is now well known as the Lunana region due to the 1994 GLOF. As many as 154 glaciers have been identified which feed the Pho Chu (Figure 7.5). The largest glacier, Tshoju Glacier (Pho_gr76), is located at the eastern branch of the Pho Chu at latitude 28° 7' 57.28" and longitude 90° 9' 57.67" at an elevation of 4,120 masl (glacier tongue elevation).

The western branch of the Pho Chu originates from the Tarina region flowing southeasterly along Tarina Valley. In total there are 71 glaciers feeding the western branch of the Pho Chu. The largest glacier on the western branch of the Pho Chu is Wachey Glacier (Pho_gr 68) with a length of 20.12 km and covering an area of 38.52 sq.km. It advanced much further south than its counterparts in eastern Lunana during the Little Ice Age. Glaciers Pho_gr 31 to 68 lie south of Tsendagang and east of Gangla Kharchung. Two prominent glacial lakes are associated with the glaciers in the region. These lakes are known to local people as Mouzom Tsho and referred to by Gansser (1970) as Tarina lakes.

The most dominant aspects of the glaciers are northeast, southeast, and southwest, in descending order. The north aspect glaciers are fewest in number (Table 7.9).

The eastern branch of the Pho Chu originates from eastern Lunana region and drains one of the remote parts of northern Bhutan. It flows through the wide inhabited valley of Thanza. There are several glaciers in this region, but the most prominent ones are Tshoju Glacier (Pho_gr 76), Chunami Glacier (Pho_gr 72), Bechung Glacier (Pho_gr 79), Raphstreng Glacier (Pho_gr 80), Thorthomi Glacier (Pho_gr 81), Lugge Glacier (Pho_gr 82), Drukchong Glacier (Pho_gr 83), and Yaksagang Glacier (Pho_gr 84). Tshoju Glacier terminates against the southwest–northeast trending Lunana Valley. In the geological past

Table 7.9: Summary of glaciers in the Pho Chu Sub-basin on the basis of aspect								
Aspect	N	NE	NW	E	W	S	SE	SW
Number of glacier	5	36	24	8	13	11	29	28
Area (km ²)	7.52	27.58	32.78	9.73	16.18	115.67	77.95	46.15
Area (%)	2.25	8.26	9.82	2.91	4.85	34.68	23.37	13.83
Maximum area (km ²)	2.60	3.23	7.74	4.29	5.09	49.27	38.54	14.99
Minimum area (km ²)	0.20	0.05	0.07	0.04	0.06	0.14	0.11	0.13
Maximum length (m)	2819	3573	6534	3792	3526	16 212	20 117	7529
Minimum length (m)	570	501	368	332	389	432	458	595
Highest elevation (masl)	5880	5855	5638	5685	5710	5471	6949	6949
Mean elevation (masl)	5387	5152	5138	5239	5225	5248	5217	5306
Tongue elevation (masl)	5120	4340	4640	4800	4960	4120	4120	4600
Ice reserve (km ³)	0.396	1.346	2.142	0.542	0.891	14.434	8.711	3.410

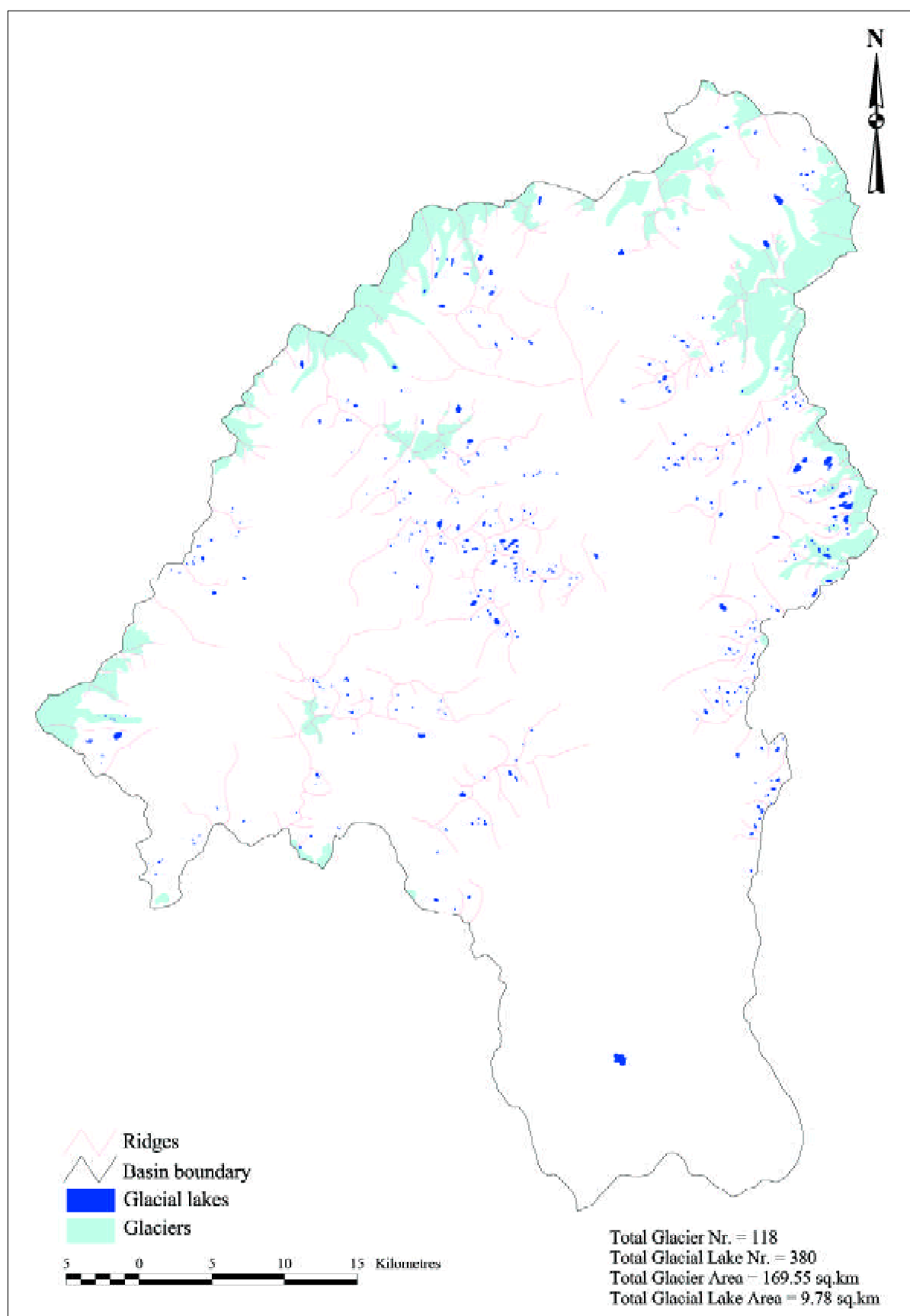


Figure 7.4: Glaciers and glacial lakes of the Mo Chu Sub-basin

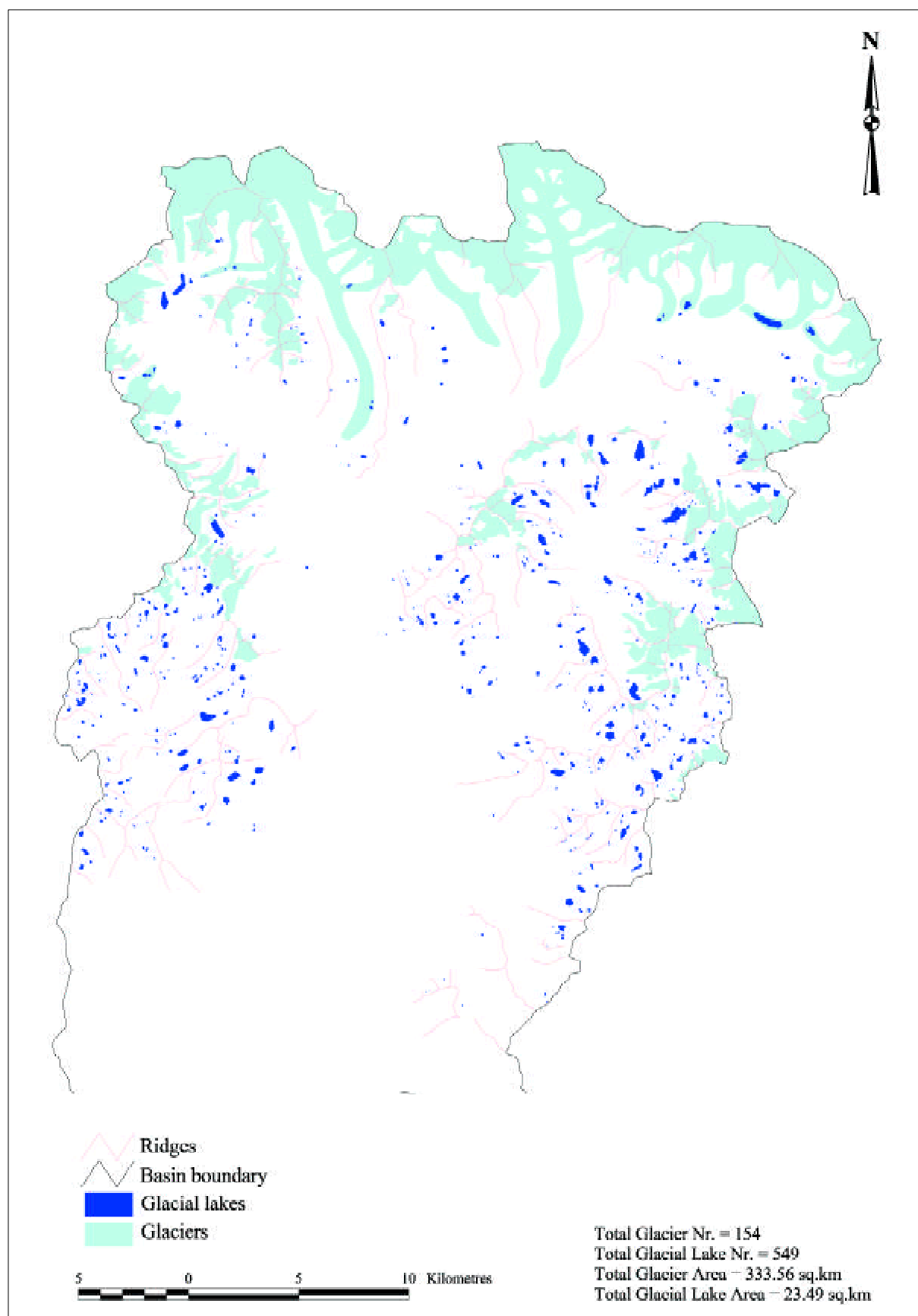


Figure 7.5: Glaciers and glacial lakes of the Pho Chu Sub-basin

the glacier advanced below Tshoju village and once dammed the eastern branch of the Pho Chu. This is evidenced by the vast lacustrine deposit in the Tshoju Plains. In the Pho Chu Sub-basin there are 115 mountain glaciers, 18 ice apron glaciers, and 11 valley glaciers; 76.03% of the ice reserve is with the valley glaciers and 23.41% with the mountain glaciers (Table 7.10).

Glacier type	Number		Area				Ice reserve	
	Number	%	km ²	%	of largest glacier	of smallest glacier	km ³	%
Mountain	115	74.68	137.52	41.23	6.90	0.05	7.46	23.41
Ice cap	3	1.95	0.39	0.12	0.20	0.14	0.01	0.03
Ice apron	18	11.69	4.85	1.45	1.53	0.20	0.15	0.47
Niche	4	2.60	0.33	0.10	0.10	0.06	0.01	0.03
Cirque	3	1.95	0.51	0.15	0.24	0.12	0.01	0.03
Valley	11	7.14	189.97	56.95	49.27	1.48	24.23	76.03
Total	154		333.56				31.87	

The Mangde Chu Sub-basin

The Mangde Chu is the western branch of the Manas River. The headwaters of the Mangde Chu are separated from those of the Pho Chu eastern branch (Lunana) by the north–south trending Yaksagang-Gophula-Pele La Range. The north–south trending Gangkarpuensum-Djulela-Yuto La Ridge separates the Mangde Chu from the Chamkhar Chu. In the northern region the Mangde Chu has three branches, two of which have their origins in glaciated and snow-covered terrain. The main branch of the Mangde Chu originates from a large valley glacier south of Kang Ri Summit (7,239 masl). The aspect of the glaciers is distributed in all directions. The highest number (28) of glaciers is in the northeast aspect and the lowest number (5) of glaciers is in the north aspect (Table 7.11).

Aspect	N	NE	NW	E	W	S	SE	SW
Number of glacier	5	28	19	9	13	22	15	25
Area (km ²)	2.05	22.39	6.41	5.22	8.15	72.85	14.85	46.00
Area (%)	1.40	15.26	4.37	3.56	5.56	49.66	10.07	10.12
Maximum area (km ²)	0.79	3.97	3.59	1.65	2.52	44.11	3.30	3.39
Mean area (km ²)	0.23	0.80	0.34	0.58	0.63	3.31	0.98	0.59
Minimum area (km ²)	0.10	0.00	0.00	0.10	0.10	0.00	0.00	0.00
Maximum length (m)	1788	3369	4180	2316	2358	10561	3131	3298
Minimum length (m)	424	182	276	525	241	386	305	404
Highest elevation (masl)	5710	5868	5640	5868	5868	5760	5688	6580
Mean elevation (masl)	5264	5323	5311	5429	5314	5352	5385	5325
Tongue elevation (masl)	5020	4500	4960	5080	5000	4720	4840	4950
Ice reserve (km ³)	0.057	1.108	0.307	0.210	0.377	8.462	0.756	0.646

The Mangde Chu Sub-basin has a total of 140 glaciers occupying an area of 146.69 sq.km (Figure 7.6). The majority of the glaciers are mountain glaciers (Table 7.12). Only one valley glacier has been recognised in this sub-basin. This is the largest glacier of the sub-basin with a length of 10.56 km and an area of 44.11 sq.km. Glacier tongue elevations in the sub-basin range from 4,500 masl to 5,080 masl.

The Chamkhar Chu Sub-basin

The Chamkhar Chu originates from the glacier south of the water divide separating Tibet from Bhutan's northern territory. The Chamkhar Chu drains the whole of Bumthang Dzongkhag. It has one western branch and two eastern branches. The western branch has its source from the glaciers of Gangkar Punsum region and the eastern branches have their sources from the glaciers south of the Monla Karchung La Range.

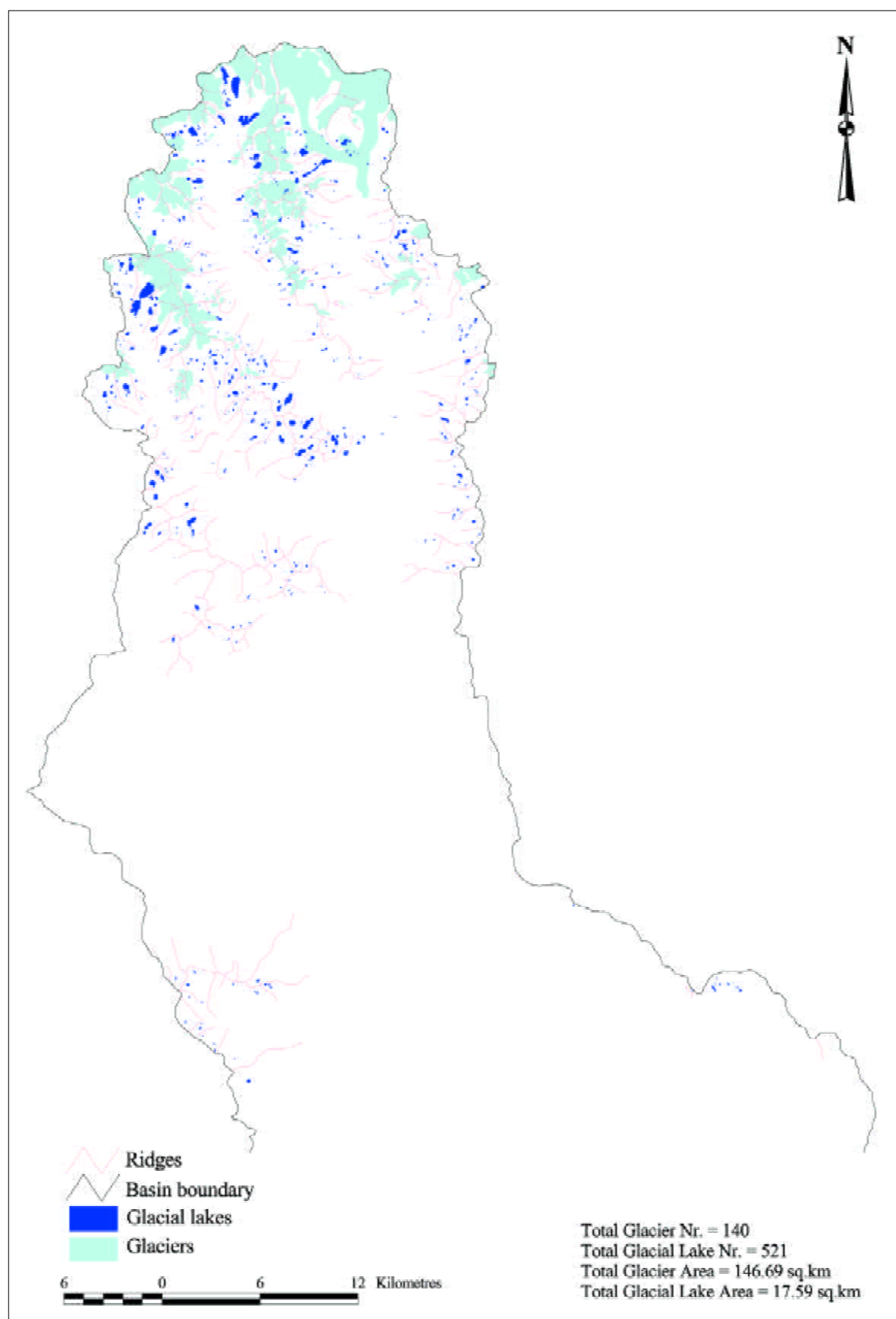


Figure 7.6: Glaciers and glacial lakes of the Mangde Chu Sub-basin

Table 7.12: Distribution of glaciers by type in the Mangde Chu Sub-basin								
Glacier type	Number		Area				Ice reserve	
	Number	%	km ²	%	Of largest glacier	of smallest glacier	km ³	%
Mountain	92	65.71	96.20	65.58	4.28	0.03	4.968	41.67
Ice apron	12	8.57	1.44	0.98	0.33	0.02	0.030	0.25
Ice cap	9	6.43	2.47	1.68	0.85	0.04	0.072	0.60
Cirque	3	2.14	0.46	0.31	0.21	0.10	0.010	0.08
Niche	23	16.43	2.01	1.37	0.18	0.03	0.033	0.28
Valley	1	0.70	44.11	30.1	44.11	44.11	6.810	57.10
Total	140		146.69				11.923	

The aspect of the glaciers is distributed in all directions. The highest number (24) of glaciers is in the northeast aspect followed by the southeast (22) and southwest (20) (Table 7.13 and Figure 7.7). There is only one glacier both east and south aspects. At the source of the Chamkhar Chu western branch a number of glaciers exist, the largest being a valley glacier, Cham_gr 25, lying at an elevation of 4,582 masl (glacier tongue elevation), east of Kang Ri Summit (7,239 masl) and oriented southeast. This glacier occupies an area of 26.71 sq.km and is 8.9 km long. The Chamkhar Chu eastern branch also has many glaciers at its source, the largest is again a valley glacier, Cham_gr 71 (Chubda Glacier), oriented southwest. Within this glacier there are number of supraglacial lakes which were observed during an expedition in August 1999 (Karma 1999). Out of the 94 glaciers inventoried in this sub-basin, 70 are mountain glaciers, 16 are niche, five are ice apron, and three are valley glaciers. The three valley glaciers contain 64.53% of the ice reserve (Table 7.14).

Table 7.13: Summary of glaciers in the Chamkhar Chu Sub-basin on the basis of aspect								
Aspect	N	NE	NW	E	W	S	SE	SW
Number of glacier	3	24	18	1	5	1	22	20
Area (km ²)	0.50	8.19	6.62	0.49	3.49	0.61	47.69	36.51
Area (%)	0.48	7.87	6.36	0.47	3.35	0.59	45.81	35.07
Maximum area (km ²)	0.41	1.06	1.72	0.49	1.07	0.61	26.71	12.45
Mean area (km ²)	0.17	0.34	0.37	0.49	0.70	0.61	2.17	1.83
Minimum area (km ²)	0.00	0.10	0.10	0.50	0.40	0.61	0.10	0.10
Maximum length (m)	1155	2105	1030	665	1255	1390	8875	7985
Minimum length (m)	250	435	290	665	420	1390	165	375
Highest elevation (masl)	5550	5520	6085	5560	5550	5400	6200	6200
Mean elevation (masl)	5318	5248	5320	5380	5346	5135	5397	5428
Tongue elevation (masl)	4970	4910	4990	5200	5180	4870	4582	4800
Ice reserve (km ³)	0.013	0.249	0.234	0.016	0.134	0.021	4.717	2.728

Table 7.14: Distribution of glaciers by type in the Chamkhar Chu Sub-basin								
Glacier type	Number		Area				Ice reserve	
	Number	%	km ²	%	of largest glacier	of smallest glacier	km ³	%
Mountain	70	74.47	54.36	52.22	5.95	0.08	2.727	33.62
Ice apron	5	5.32	2.59	2.49	1.72	0.17	0.107	1.32
Niche	16	17.02	2.17	2.08	0.28	0.03	0.043	0.53
Valley	3	3.19	44.98	43.21	26.71	5.82	5.235	64.53
Total	94		104.1				8.112	

The Kuri Chu Sub-basin

A large part of the Kuri Chu headwaters lie in Tibet. Within Bhutan it has two major tributaries, the Bahilung Chu flowing southeasterly and the Khoma Chu flowing southerly. The Kuri Chu joins the Khoma Chu southeast of Lhunsi Dzong.

There are 51 glaciers that have been identified within Bhutan from satellite images in the headwaters of the Kuri Chu (Figure 7.8). They occupy a surface area of 87.62 sq.km. In terms of number southeast and northeast oriented glaciers are dominant, but in terms of area covered by glaciers the northwest and southeast aspect are significant (Table 7.15).

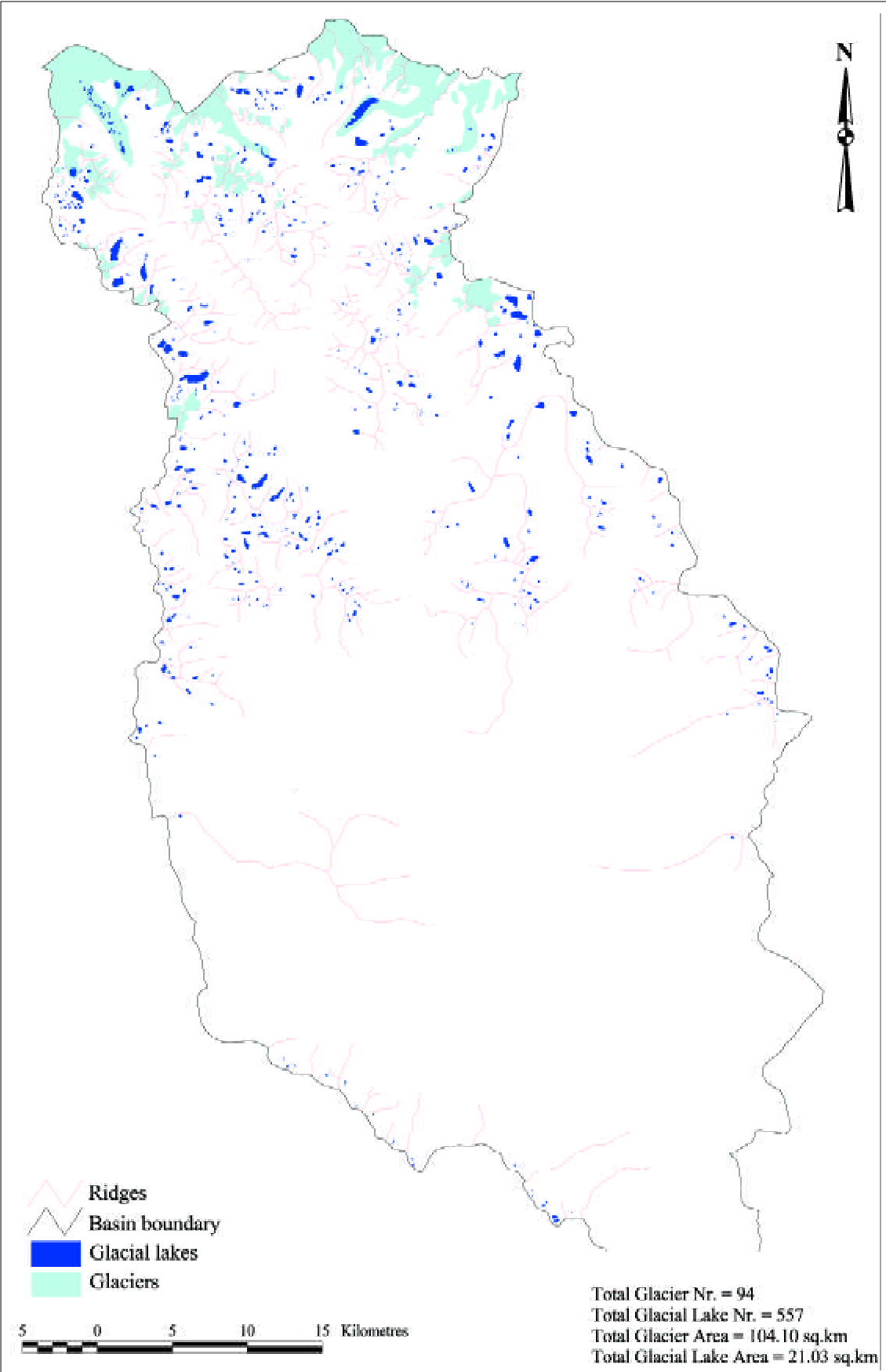


Figure 7.7: Glaciers and glacial lakes of the Chamkhar Chu Sub-basin

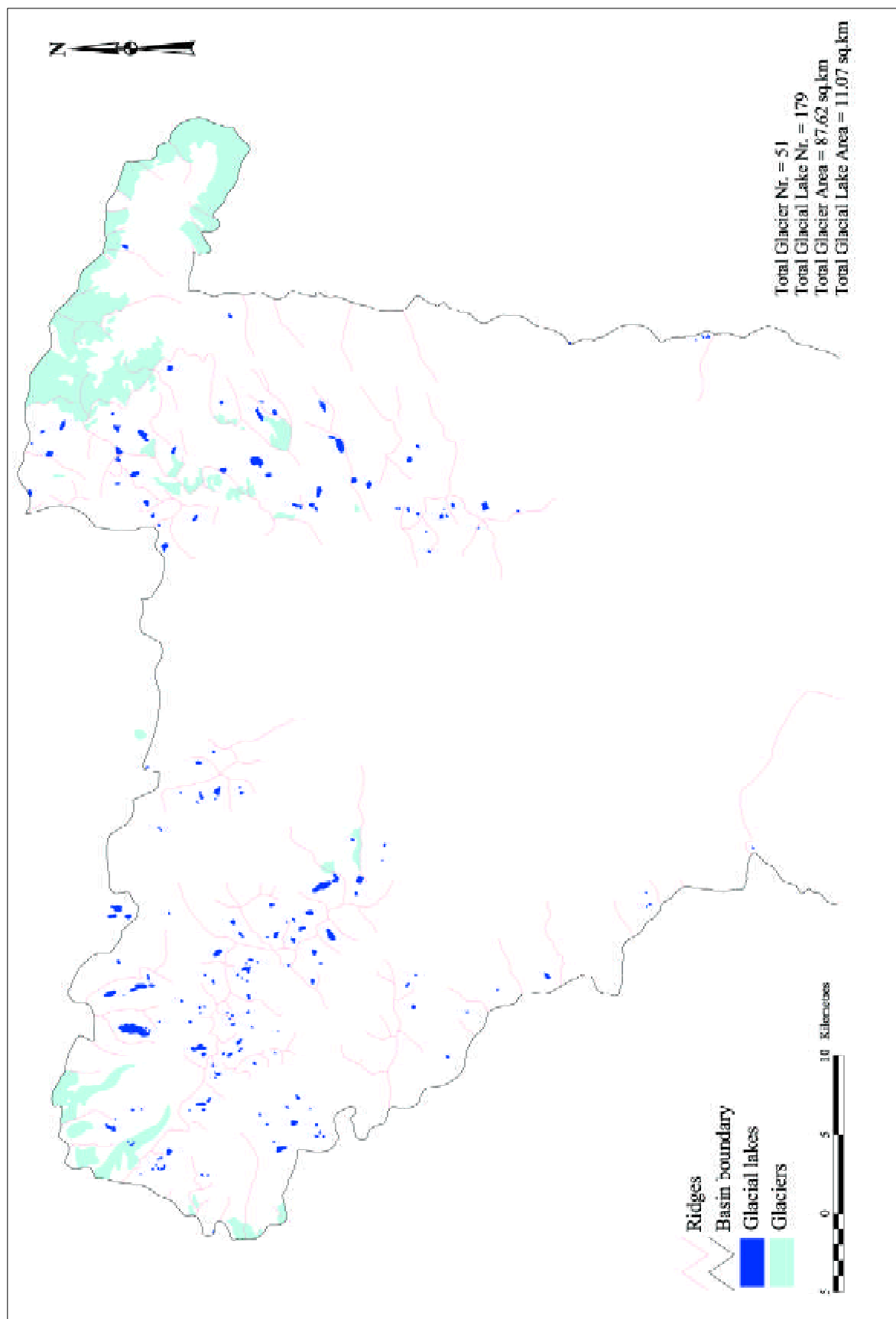


Figure 7.8: Glaciers and glacial lakes of the Kuri Chu Sub-basin

Table 7.15: Summary of glaciers in the Kuri Chu Sub-basin on the basis of aspect								
Aspect	N	NE	NW	E	W	S	SE	SW
Number of glacier	3	10	4	2	4	5	14	9
Area (km ²)	0.97	13.02	14.82	0.84	2.44	3.12	41.08	11.33
Area (%)	1.11	14.86	16.91	0.96	2.78	3.56	46.88	12.96
Maximum area (km ²)	0.39	2.75	13.89	0.72	1.70	1.52	12.84	2.42
Mean area (km ²)	0.32	1.30	3.71	0.42	0.61	0.62	2.93	1.26
Minimum area (km ²)	0.20	0.20	0.10	0.10	0.00	0.10	0.10	0.10
Maximum length (m)	1000	2450	2150	750	1250	1550	6600	1800
Minimum length (m)	550	350	200	650	300	300	400	250
Highest elevation (m)	4610	4280	4680			5400	5765	
Mean elevation (m)		6320	6980			7900	7855	
Tongue elevation (m)		4080	4600			5000	4180	
Ice reserve (km ³)	0.026	0.655	1.497	0.029	0.110	0.132	3.427	0.610

Mountain glaciers are the dominant type in the Kuri Chu Sub-basin. They occupy an area of 72.14 sq.km and contain around 84% of the ice reserve of this sub-basin (Table 7.16).

Table 7.16: Distribution of glaciers by type in the Kuri Chu Sub-basin								
Glacier type	Number		Area				Ice reserve	
	Number	%	km ²	%	of largest glacier	of smallest glacier	km ³	%
Mountain	38	74.51	72.14	82.33	13.89	0.16	5.423	83.73
Ice apron	4	7.84	0.72	0.82	0.40	0.04	0.017	0.26
Cirque	1	1.96	0.10	0.11	0.10	0.10	0.002	0.03
Niche	4	7.84	0.48	0.55	0.13	0.11	0.008	0.12
Valley	4	7.84	14.18	16.18	6.00	0.72	1.027	15.86
Total	51		87.62				6.477	

The Dangme Chu Sub-basin

In this sub-basin only 25 glaciers have been identified, covering an area of 38.32 sq.km (Figure 7.9). None of the glaciers in this sub-basin has been physically checked to date. Most of the glaciers are mountain glaciers and east oriented glaciers seem to be the dominant type in this region (Table 7.17). The largest glacier, Dangm_gr 19, has a maximum area of 5.60 sq.km and a length of 4.43 km and is located at latitude 27° 54' 28.68" and longitude 91° 28' 50.39". A total of 2.258 km³ of ice reserve has been estimated (Table 7.18). All the glaciers have been studied from satellite images due to the unavailability of topographic maps and hence the elevations of the glaciers in this sub-basin are unknown.

Table 7.17: Summary of glaciers in Dangme Chu Sub-basin on the basis of aspect				
Aspect	NE	E	SE	SW
Number of glacier	1	11	5	8
Area (km ²)	0.98	17.01	5.99	14.56
Area (%)	2.54	44.14	15.54	37.78
Maximum area (km ²)	0.98	3.99	4.04	5.60
Mean area (km ²)	0.98	1.55	1.20	1.82
Minimum area (km ²)	1.00	0.40	0.10	0.20
Maximum length (m)	1506	2200	2382	4433
Minimum length (m)	1506	760	580	473
Ice reserve (km ³)	0.040	0.940	0.360	0.920

Table 7.18: Distribution of glaciers by type in Dangme Chu Sub-basin								
Glacier type	Number		Area				Ice reserve	
	Number	%	km ²	%	of largest glacier	of smallest glacier	km ³	%
Mountain	23	92.00	38.32	99.43	5.60	0.20	2.254	99.82
Ice apron	1	4.00	0.11	0.29	0.11	0.11	0.002	0.09
Niche	1	4.00	0.11	0.29	0.11	0.11	0.002	0.09
Total	25		38.54				2.258	

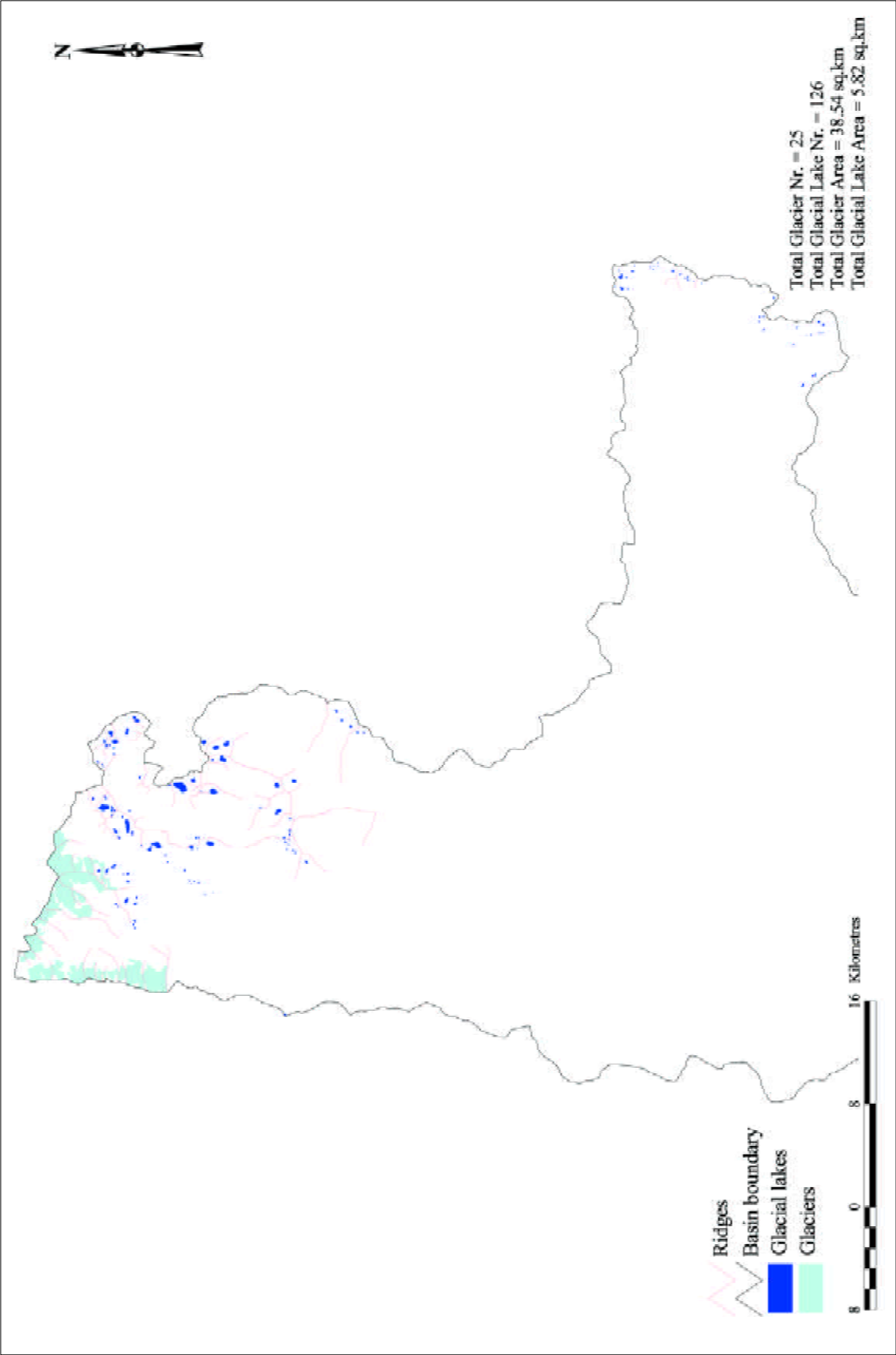


Figure 7.9: Glaciers and glacial lakes of the Dangde Chu Sub-basin

The Northern Basin

Contrary to the other rivers of Bhutan, the rivers of the Northern Basin flow from south to north. These rivers flow from Bhutan to Tibet (China). The Northern Basin is bounded by the Teri Gong –Jejekangphu Gong –Table Mountain–Kangri Mountain Range from the south.

The aspect of glaciers is distributed in all directions. The glaciers with northeast aspects are highest in number (19). The second highest number (13) of glaciers is in the northwest aspect (Figure 7.10). There are only five glaciers with north aspect. The number of glaciers in the east, west, and south aspects are three, two, and two respectively (Table 7.19). The area occupied by the northeast and northwest aspect glaciers is more than 80%. Due to unavailability of topographic maps of the Northern Basin area, the elevations of the glaciers are unknown.

The majority of the glaciers are ice apron and valley types (Table 7.20). This is the only basin in the Bhutan Himalayas which consists of a large number of valley glaciers. The valley glaciers including the mountain type make up 48% in terms of number. The area occupied by these glaciers is more than 85% (Table 7.20).

Table 7.19: Summary of glaciers in the Northern basin on the basis of aspect								
Aspect	SE	E	NW	NE	N	SW	W	S
Number of glacier	8	3	13	19	5	7	2	2
Area (km ²)	14.7	2.40	158.9	159.45	35.45	1.80	14.49	0.48
Percentage area (%)	3.81	0.62	40.98	41.12	9.14	0.46	3.74	0.12
Maximum area (km ²)	9.09	1.00	99.77	48.14	27.6	0.59	11.92	0.24
Mean area (km ²)	1.85	.80	12.22	8.39	7.09	0.26	7.25	0.24
Minimum area (km ²)	0.12	.45	0.30	0.09	0.32	0.17	2.57	0.24
Maximum length (m)	4990	910	12710	10990	8585	935	6570	460
Minimum length (m)	200	305	380	425	540	285	1790	440
Ice reserve (km ³)	1.10	0.10	25.40	19.54	4.17	0.05	1.35	0.01

Table 7.20: Glacier types in the Northern Basin								
Glacier type	Number		Area				Ice reserve	
	Number	%	km ²	%	of largest glacier	of smallest glacier	km ³	%
Mountain	10	17	70.57	18.20	20.82	1.61	6.866	13.28
Ice cap	2	3	2.25	0.58	1.30	0.95	0.099	0.19
Ice apron	23	39	14.00	3.61	2.57	0.12	0.578	1.12
Niche	3	5	0.47	0.12	0.21	0.09	0.009	0.02
Cirque	3	5	0.54	0.14	0.20	0.15	0.011	0.02
Valley	18	31	299.91	77.35	99.77	1.00	44.157	85.38
Total	59		387.74				51.720	

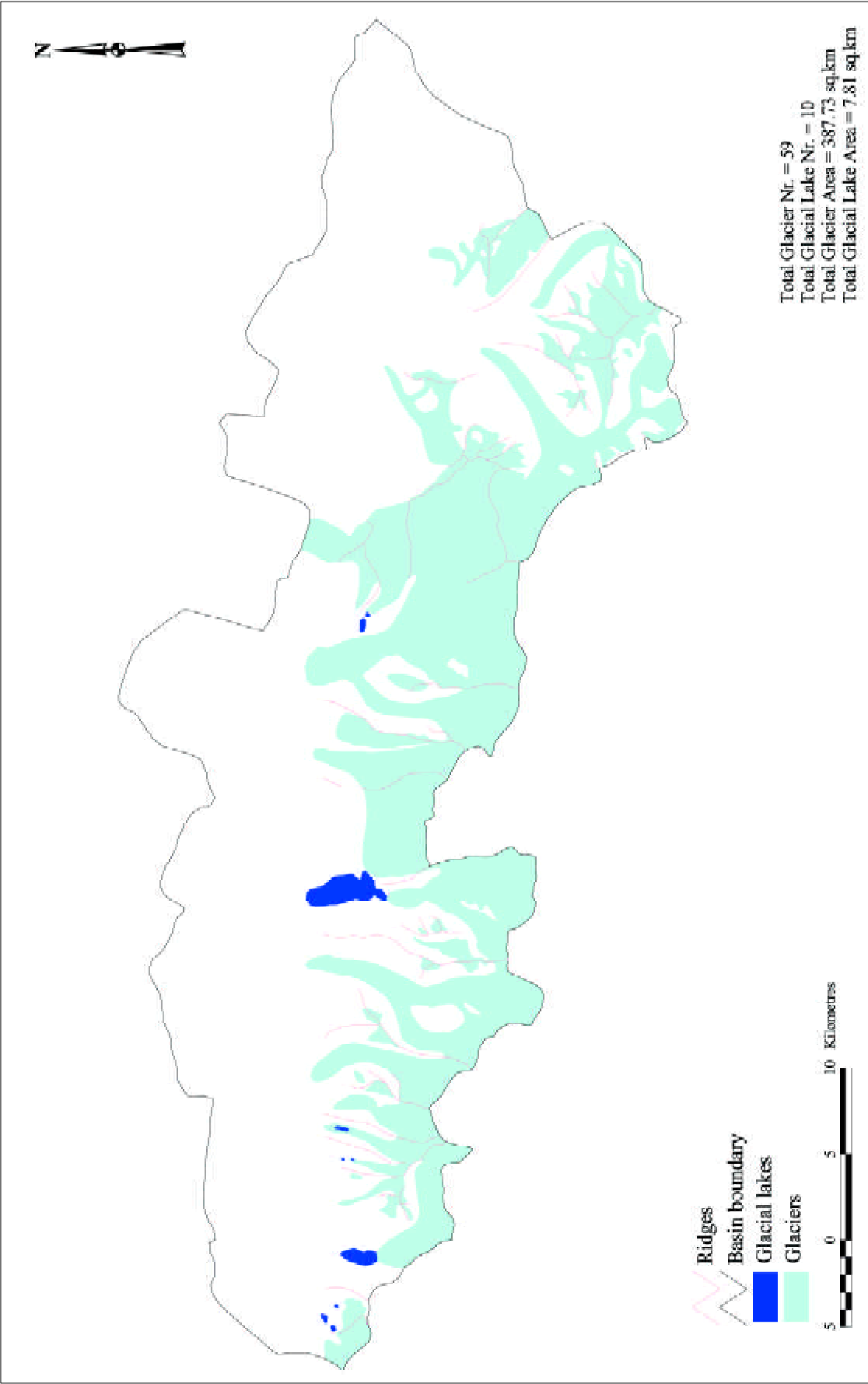


Figure 7.10: Glaciers and glacial lakes of the Northern Basin

