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Rapidly changing lake-terminating glaciers in High Mountain Asia: a dataset from 1990 to 2022

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Table S 1 Glacier type statistics (number and area) across subregions

Region	Glacier number				Glacier area (km²)							
					1990s				2022s			
	Type 1	Type 2	Type 3	Total	Type 1	Type 2	Type 3	Total	Type 1	Type 2	Type 3	Total
Central Himalaya	94	138	84	316	589.97±2.81	264.93±1.64	219.8±1.17	1074.7±3.46	552.77±2.71	244.8±1.56	202.67±1.11	1000.25±3.32
Western Himalaya	66	106	28	200	198.31±2.11	176.41±1.67	42.54±0.47	417.26±2.74	192.5±2.08	167.24±1.64	40.28±0.45	400.02±2.69
Eastern Himalaya	64	68	48	180	419.67±2.06	155.37±1.07	87.2±0.68	662.24±2.42	392.93±1.97	136.97±0.98	78.65±0.63	608.55±2.29
Gangdise Mountains	64	77	50	191	35.19±0.32	45.65±0.37	33.34±0.33	114.17±0.59	31.79±0.31	40.11±0.34	29.53±0.31	101.44±0.55
Hindu Kush	61	75	12	148	26.49±0.31	45.82±0.41	8.71±0.17	81.02±0.54	23.58±0.29	41.34±0.39	7.83±0.16	72.74±0.51
Nyainqentanglha	55	126	48	229	677.08±3.76	368.21±2.96	164.46±1.28	1209.75±4.95	650.54±3.73	350.51±2.91	154.73±1.22	1155.78±4.89
Altun Shan/Eastern Kunlun Shan	32	30	3	65	197.95±0.85	62.54±0.42	4.09±0.09	264.59±0.95	194.08±0.84	59.98±0.41	3.95±0.09	258.02±0.93
Northern/Western Tien Shan	32	73	40	145	31.78±0.37	63.81±0.53	37.44±0.35	133.03±0.74	28.79±0.35	58.39±0.51	33.45±0.33	120.63±0.7
Western Pamir	30	59	17	106	93.74±0.95	99.99±0.84	16.58±0.29	210.3±1.09	89.95±0.93	94.04±0.8	15.33±0.28	199.33±1.26
Central Tien Shan	25	49	17	91	733.67±10.9	53.48±0.64	29.86±0.6	817.01±10.94	729.83±10.9	49.1±0.61	27.78±0.57	806.71±10.93
Qilian Shan	21	7	10	38	119.22±0.92	11.38±0.19	59.35±0.54	189.95±1.08	116.6±0.9	10.31±0.18	57.66±0.52	184.57±1.05
Eastern Tien Shan	18	46	18	82	33.23±0.54	39.06±0.38	29.91±0.54	102.2±0.85	30.49±0.52	35.32±0.36	27.46±0.52	93.27±0.82
Karakoram	18	18	6	42	66.51±0.78	102.9±0.99	128.82±2.25	298.24±2.58	65.1±0.76	100.62±0.97	128.1±2.25	293.82±2.56
Tanggula Shan	17	17	27	61	130.26±0.94	14.97±0.24	62.7±0.54	207.93±1.11	124.33±0.91	13.75±0.23	58.63±0.52	196.7±1.07
Tibetan Interior Mountains	17	34	9	60	96.32±0.72	112.16±0.74	53.53±0.49	262.02±1.14	95.32±0.71	109.47±0.73	51.62±0.46	256.4±1.12
Dzhungarsky Alatau	16	45	14	75	12.85±0.2	32.15±0.31	17.71±0.26	62.71±0.45	10.78±0.18	28.49±0.29	15.41±0.24	54.68±0.42
Hengduan Shan	16	65	27	108	10.75±0.18	49.63±0.5	27.82±0.31	88.2±0.61	8.03±0.16	42.71±0.47	22.99±0.27	73.72±0.57
Pamir Alay	11	29	8	48	5.79±0.12	27.8±0.38	3.42±0.11	37±0.42	5.12±0.12	25.74±0.37	3.05±0.11	33.91±0.4
Western Kunlun Shan	7	0	0	7	104.03±1.08	0	0	104.03±1.08	103.14±1.08	0	0	103.14±1.08
Eastern Pamir	2	5	1	8	6.89±0.22	14.14±0.28	0.39±0.03	21.43±0.35	6.82±0.21	13.78±0.27	0.37±0.03	20.97±0.35
Eastern Tibetan Mountains	1	6	1	8	2.35±0.08	5.75±0.14	0.76±0.05	8.86±0.16	2.12±0.08	4.83±0.14	0.64±0.04	7.59±0.16
Total	667	1073	468	2208	3592.05±12.49	1746.17±4.43	1028.43±3.28	6366.64±13.65	3454.59±12.43	1627.49±4.3	960.13±3.18	6042.24±13.53

Table S 2 Area and number distribution of three glacier types across different size classes

Glacier size (km²)	Glacier number (1990s)				Glacier number (2022s)				Glacier area (km²)(1990s)				Glacier area (km²)(2022s)			
	Type 1	Type 2	Type 3	Total	Type 1	Type 2	Type 3	Total	Type 1	Type 2	Type 3	Total	Type 1	Type 2	Type 3	Total
<0.05	8	9	4	21	20	33	19	72	0.31±0.03	0.33±0.03	0.15±0.02	0.78±0.04	0.72±0.04	1.05±0.05	0.69±0.04	2.46±0.07
0.05-0.1	28	43	26	97	37	72	28	137	2.22±0.07	3.24±0.08	1.86±0.06	7.32±0.12	2.72±0.08	5.36±0.11	2.07±0.06	10.15±0.15
0.1-0.5	166	437	136	739	168	442	151	761	44.18±0.34	118.86±0.54	39.44±0.31	202.48±0.71	45.06±0.34	118.54±0.54	43.13±0.33	206.73±0.72
0.5-1	126	239	101	466	118	205	86	409	92.8±0.53	166.86±0.72	71.75±0.47	331.41±1.01	84.4±0.52	141.21±0.66	60.88±0.44	286.49±0.94
1-5	197	277	154	628	188	256	141	585	478.95±1.49	563.75±1.61	343.68±1.24	1386.38±2.52	459.59±1.47	515.28±1.55	318.5±1.18	1289.21±2.44
5-10	71	43	30	144	67	41	26	134	498.24±1.92	303.8±1.57	207.84±1.19	1009.87±2.75	455.09±1.82	287.6±1.51	180.33±1.09	927.97±2.56
10-50	63	23	16	102	61	22	16	99	1347.15±4.57	432.18±2.45	248.78±1.6	2028.11±5.43	1268.56±4.37	432.17±2.49	240.09±1.54	1931.43±5.26
50-100	5	2	0	7	5	2	0	7	343.42±2.96	157.16±2.78	0	500.58±4.06	332.14±2.97	155.79±2.76	0	487.93±4.05
>100	3	0	1	4	3	0	1	4	784.78±10.96	0	114.93±2.23	899.7±11.18	785.42±10.96	0	114.44±2.22	899.86±11.18
Total	667	1073	468	2208	667	1073	468	2208	3592.05±12.49	1746.17±4.43	1028.43±3.28	6366.64±13.65	3454.59±12.43	1627.49±4.3	960.13±3.18	6042.24±13.53

Table S 3 Glacial lake type statistics (number and area) across subregions

Region	Lake number (1990s)				Lake number (2022s)				Lake area (km²) (1990s)				Lake area (km²) (2022s)			
	Type 1	Type 2	Type 3	Total	Type 1	Type 2	Type 3	Total	Type 1	Type 2	Type 3	Total	Type 1	Type 2	Type 3	Total
Central Himalaya	91	0	86	177	91	149	80	320	46.47±0.38	0	13.83±0.2	60.29±0.43	76.89±0.51	10.02±0.16	15.7±0.21	102.62±0.58
Western Himalaya	65	0	28	93	65	107	27	199	4.17±0.11	0	1.2±0.05	5.38±0.12	9.02±0.15	4.13±0.09	1.51±0.06	14.66±0.19
Eastern Himalaya	57	0	50	107	56	75	49	180	23.92±0.26	0	5.05±0.11	28.98±0.29	36.75±0.36	10.89±0.18	6.55±0.13	54.19±0.42
Gangdise Mountains	65	0	51	116	65	79	51	195	3.72±0.1	0	3.19±0.08	6.91±0.13	4.49±0.1	2.32±0.07	2.67±0.07	9.48±0.14
Hindu Kush	60	0	12	72	61	75	12	148	2.97±0.08	0	0.61±0.04	3.58±0.09	4.83±0.11	1.81±0.06	0.49±0.04	7.13±0.12
Nyainqentanglha	52	0	51	103	52	135	49	236	12.53±0.18	0	5.78±0.13	18.31±0.22	28.57±0.3	8.16±0.14	7.52±0.14	44.25±0.36
Altun Shan/Eastern Kunlun Shan	33	0	3	36	32	38	3	73	4.83±0.14	0	0.17±0.02	5±0.14	5.68±0.14	1.06±0.05	0.11±0.02	6.85±0.15
Northern/Western Tien Shan	32	0	41	73	31	75	39	145	1.15±0.05	0	1.44±0.05	2.6±0.07	2.3±0.07	1.97±0.06	1.51±0.06	5.77±0.11
Western Pamir	28	0	19	47	28	60	19	107	1.27±0.05	0	0.91±0.04	2.17±0.07	2.81±0.08	3.04±0.08	0.89±0.04	6.74±0.12
Central Tien Shan	26	0	17	43	25	49	16	90	10.78±0.17	0	0.71±0.04	11.49±0.18	10.37±0.21	1.81±0.06	0.81±0.04	13±0.22
Qilian Shan	20	0	11	31	20	8	11	39	2.81±0.07	0	0.95±0.04	3.76±0.09	4.24±0.1	0.26±0.02	0.88±0.04	5.37±0.11
Eastern Tien Shan	17	0	20	37	17	47	16	80	0.76±0.04	0	0.73±0.04	1.49±0.05	1.72±0.06	1.56±0.05	0.8±0.04	4.08±0.09
Karakoram	19	0	5	24	19	17	3	39	1.69±0.07	0	0.32±0.03	2.02±0.07	2.64±0.08	0.98±0.04	0.05±0.01	3.66±0.09
Tanggula Shan	17	0	28	45	17	17	26	60	3.1±0.08	0	2.28±0.09	5.38±0.12	6.15±0.12	0.57±0.03	1.35±0.05	8.07±0.14
Tibetan Interior Mountains	14	0	9	23	14	35	7	56	2.56±0.11	0	0.94±0.05	3.5±0.12	3.58±0.14	1.75±0.06	0.91±0.04	6.23±0.16
Dzhungarsky Alatau	14	0	16	30	14	48	15	77	0.37±0.03	0	1.17±0.05	1.54±0.06	1.03±0.05	1.38±0.05	1.25±0.05	3.66±0.09
Hengduan Shan	15	0	28	43	15	66	27	108	0.71±0.04	0	1.63±0.06	2.35±0.07	1.26±0.06	1.84±0.06	1.91±0.07	5.01±0.11
Pamir Alay	12	0	8	20	12	32	8	52	0.5±0.03	0	0.34±0.02	0.84±0.02	0.77±0.04	0.94±0.04	0.33±0.02	2.03±0.05
Western Kunlun Shan	7	0	0	7	7	0	0	7	3.17±0.08	0	0	3.17±0.08	3.59±0.09	0	0	3.59±0.09
Eastern Pamir	3	0	1	4	3	5	1	9	0.22±0.03	0	0.05±0.01	0.26±0.03	0.33±0.02	0.16±0.02	0.04±0.01	0.53±0.03
Eastern Tibetan Mountains	1	0	1	2	1	6	1	8	0.1±0.01	0	0.04±0.01	0.14±0.02	0.19±0.02	0.21±0.02	0.02±0.01	0.42±0.03
Total	648	0	485	1133	645	1123	460	2228	127.82±0.61	0	41.33±0.32	169.15±0.69	207.18±0.82	54.85±0.35	45.31±0.34	307.34±0.96

Table S 4 Area and number distribution of three lake types across different size classes

Glacier size (km²)	Lake number								Lake area (km²)							
	1990s				2022s				1990s				2022s			
	Type 1	Type 2	Type 3	Total	Type 1	Type 2	Type 3	Total	Type 1	Type 2	Type 3	Total	Type 1	Type 2	Type 3	Total
<0.05	338	0	289	627	197	887	245	1329	7.62±0.12	0	7.5±0.12	15.12±0.16	5.71±0.11	20.58±0.19	6.13±0.11	32.42±0.25
0.05-0.1	96	0	93	189	145	155	92	392	6.58±0.12	0	6.45±0.12	13.03±0.17	10.02±0.15	10.81±0.15	6.56±0.12	27.39±0.24
0.1-0.5	157	0	90	247	204	72	111	387	32.46±0.28	0	17.77±0.21	50.24±0.34	47.07±0.35	13.19±0.17	23.25±0.24	83.51±0.46
0.5-1	30	0	12	42	47	6	9	62	20.03±0.25	0	8.44±0.17	28.47±0.3	31.18±0.32	4.43±0.14	5.67±0.13	41.28±0.37
>1	27	0	1	28	52	3	3	58	61.12±0.45	0	1.17±0.06	62.29±0.45	113.19±0.65	5.84±0.12	3.7±0.12	122.73±0.67
Total	648	0	485	1133	645	1123	460	2228	127.82±0.61	0	41.33±0.32	169.15±0.69	207.18±0.82	54.85±0.35	45.31±0.34	307.34±0.96

Table S 5 Area changes of different glacier types in each subregion (1990–2022)

Region	Area loss(km²)				Area loss(%)			
	Type 1	**Type 2**	**Type 3**	**Total**	**Type 1**	**Type 2**	**Type 3**	**Total**
Central Himalaya	37.2±3.91	20.13±2.26	17.13±1.62	74.46±4.8	6.31	7.6	7.79	6.93
Western Himalaya	5.81±2.97	9.17±2.34	2.26±0.65	17.24±3.84	2.93	5.2	5.31	4.13
Eastern Himalaya	26.74±2.85	18.41±1.45	8.55±0.93	53.7±3.33	6.37	11.85	9.8	8.11
Gangdise Mountains	3.39±0.44	5.54±0.5	3.8±0.46	12.73±0.81	9.65	12.14	11.41	11.16
Hindu Kush	2.91±0.43	4.48±0.56	0.88±0.23	8.27±0.74	10.98	9.78	10.13	10.21
Nyainqentanglha	26.54±5.29	17.7±4.15	9.72±1.77	53.96±6.95	3.92	4.81	5.91	4.46
Altun Shan/Eastern Kunlun Shan	3.87±1.19	2.57±0.59	0.14±0.13	6.58±1.33	1.95	4.1	3.38	2.48
Northern/Western Tien Shan	2.99±0.51	5.42±0.74	3.99±0.49	12.4±1.02	9.42	8.49	10.66	9.32
Western Pamir	3.79±1.33	5.95±1.16	1.24±0.4	10.98±1.81	4.04	5.95	7.51	5.22
Central Tien Shan	3.84±15.42	4.38±0.88	2.08±0.83	10.3±15.47	0.52	8.19	6.97	1.26
Qilian Shan	2.62±1.28	1.07±0.27	1.7±0.75	5.39±1.51	2.2	9.4	2.86	2.84
Eastern Tien Shan	2.74±0.75	3.74±0.52	2.45±0.75	8.93±1.18	8.25	9.58	8.18	8.74
Karakoram	1.41±1.09	2.29±1.39	0.72±3.18	4.42±3.64	2.12	2.22	0.56	1.48
Tanggula Shan	5.94±1.31	1.22±0.33	4.07±0.75	11.23±1.55	4.56	8.18	6.49	5.4
Tibetan Interior Mountains	1.01±1.02	2.69±1.04	1.92±0.68	5.62±1.61	1.04	2.4	3.58	2.14
Dzhungarsky Alatau	2.07±0.26	3.66±0.43	2.3±0.36	8.03±0.62	16.1	11.38	12.99	12.8
Hengduan Shan	2.73±0.24	6.92±0.69	4.83±0.41	14.48±0.84	25.34	13.95	17.37	16.42
Pamir Alay	0.67±0.17	2.06±0.53	0.37±0.15	3.1±0.58	11.55	7.4	10.75	8.36
Western Kunlun Shan	0.89±1.53	0	0	0.89±1.53	0.86	0	0	0.86
Eastern Pamir	0.08±0.3	0.36±0.39	0.02±0.04	0.46±0.49	1.1	2.57	5.37	2.15
Eastern Tibetan Mountains	0.23±0.11	0.92±0.19	0.12±0.06	1.27±0.23	9.81	15.94	16.33	14.35
Total	137.46±17.62	118.68±6.18	68.29±4.58	324.43±19.23	3.83	6.8	6.64	5.1

Table S 6 Area and number changes of three glacier types across different size classes

Glacier size	Number change(count)				Area change(km²)				Area change(%)			
(km²)	Type 1	Type 2	Type 3	Total	Type 1	Type 2	Type 3	Total	Type 1	Type 2	Type 3	Total
<0.05	12	24	15	51	0.41±0.05	0.73±0.05	0.54±0.04	1.68±0.08	133.95	224.58	367.1	215.87
0.05-0.1	9	29	2	40	0.58±0.1	2.04±0.13	0.21±0.09	2.83±0.19	26.17	62.92	11.3	38.68
0.1-0.5	2	5	15	22	1.67±0.48	-1.1±0.77	3.68±0.46	4.25±1.02	3.78	-0.93	9.33	2.1
0.5-1	-8	-34	-15	-57	-8.41±0.74	-25.65±0.97	-10.87±0.64	-44.93±1.38	-9.06	-15.37	-15.15	-13.56
1-5	-9	-21	-13	-43	-19.48±2.11	-52.52±2.21	-25.17±1.71	-97.17±3.5	-4.07	-9.32	-7.32	-7.01
5-10	-4	-2	-4	-10	-38.2±2.62	-16.19±2.18	-27.51±1.57	-81.9±3.75	-7.67	-5.33	-13.24	-8.11
10-50	-2	-1	0	-3	-63.39±6.38	-24.61±3.4	-8.69±2.22	-96.69±7.56	-4.71	-5.69	-3.49	-4.77
50-100	0	0	0	0	-11.28±4.19	-1.37±3.92	0	-12.65±5.74	-3.28	-0.87		-2.53
>100	0	0	0	0	0.64±15.5	0	-0.48±3.15	0.16±15.82	0.08		-0.42	0.02
Total	0	0	0	0	-137.46±17.62	-118.67±6.17	-68.29±4.57	-324.42±27.18	-3.83	-6.8	-6.64	-5.1

Table S 7 Area changes of different glacial lake types in each subregion (1990–2022)

Region	Area change（km²）				Area change（%）		
	Type 1	Type 2	Type 3	Total	Type 1	Type 3	Total
Central Himalaya	30.42±0.64	10.02±0.16	1.88±0.29	42.32±0.72	65.46	13.6	70.19
Western Himalaya	4.84±0.19	4.13±0.09	0.31±0.07	9.28±0.22	115.95	25.8	172.62
Eastern Himalaya	12.83±0.45	10.89±0.18	1.49±0.17	25.22±0.51	53.63	29.49	87.04
Gangdise Mountains	0.77±0.14	2.32±0.07	-0.52±0.11	2.57±0.19	20.7	-16.32	37.21
Hindu Kush	1.86±0.13	1.81±0.06	-0.11±0.05	3.55±0.15	62.57	-18.1	99.15
Nyainqentanglha	16.04±0.35	8.16±0.14	1.74±0.19	25.95±0.42	128.03	30.11	141.75
Altun Shan/Eastern Kunlun Shan	0.85±0.2	1.06±0.05	-0.05±0.02	1.86±0.21	17.59	-30.3	37.21
Northern/Western Tien Shan	1.14±0.09	1.97±0.06	0.07±0.08	3.17±0.13	98.76	4.86	122.14
Western Pamir	1.54±0.09	3.04±0.08	-0.02±0.06	4.57±0.14	121.66	-2.2	210.24
Central Tien Shan	-0.41±0.27	1.81±0.06	0.11±0.06	1.51±0.28	-3.8	15.59	13.14
Qilian Shan	1.43±0.12	0.26±0.02	-0.07±0.06	1.61±0.14	50.93	-7.34	42.8
Eastern Tien Shan	0.96±0.08	1.56±0.05	0.07±0.06	2.59±0.11	126.23	9.62	174
Karakoram	0.94±0.11	0.98±0.04	-0.28±0.03	1.64±0.12	55.52	-86.41	81.3
Tanggula Shan	3.04±0.14	0.57±0.03	-0.93±0.1	2.69±0.18	98.01	-40.83	50
Tibetan Interior Mountains	1.02±0.18	1.75±0.06	-0.03±0.07	2.73±0.2	39.92	-3.18	78.03
Dzhungarsky Alatau	0.66±0.06	1.38±0.05	0.08±0.07	2.12±0.1	176.38	6.85	137.53
Hengduan Shan	0.55±0.07	1.84±0.06	0.28±0.09	2.66±0.13	76.97	17.13	113.23
Pamir Alay	0.27±0.05	0.94±0.04	-0.02±0.03	1.19±0.07	54.26	-5.82	141.49
Western Kunlun Shan	0.42±0.12	0	0	0.42±0.12	13.26		13.26
Eastern Pamir	0.11±0.04	0.16±0.02	-0.01±0.01	0.26±0.04	50.87	-20.66	98.25
Eastern Tibetan Mountains	0.08±0.02	0.21±0.02	-0.01±0.01	0.28±0.04	77.14	-27.51	199.92
Total	79.36±1.02	54.85±0.35	3.98±0.47	138.19±1.18	62.09	9.63	81.7

Table S 8 Area and number changes of proglacial lakes of three glacier types across different size classes

Glacier size (km²)	Number change				Area change(km²)				Area change(%)		
	Type 1	Type 2	Type 3	Total	Type 1	Type 2	Type 3	Total	Type 1	Type 3	Total
<0.05	-141	887	-44	702	-1.91±0.16	20.58±0.19	-1.36±0.16	17.31±0.3	-25.07	-18.14	114.49
0.05-0.1	49	155	-1	203	3.44±0.19	10.81±0.15	0.11±0.17	14.36±0.29	52.27	1.71	110.23
0.1-0.5	47	72	21	140	14.61±0.44	13.19±0.17	5.47±0.32	33.27±0.57	45	30.77	66.22
0.5-1	17	6	-3	20	11.15±0.4	4.43±0.14	-2.76±0.21	12.82±0.48	55.66	-32.72	45.04
>1	25	3	2	30	52.07±0.79	5.84±0.12	2.53±0.13	60.44±0.81	85.19	215.49	97.02
Total	-3	1123	-25	1095	79.36±1.02	54.85±0.35	3.98±0.46	138.19±1.18	62.09	9.63	81.7

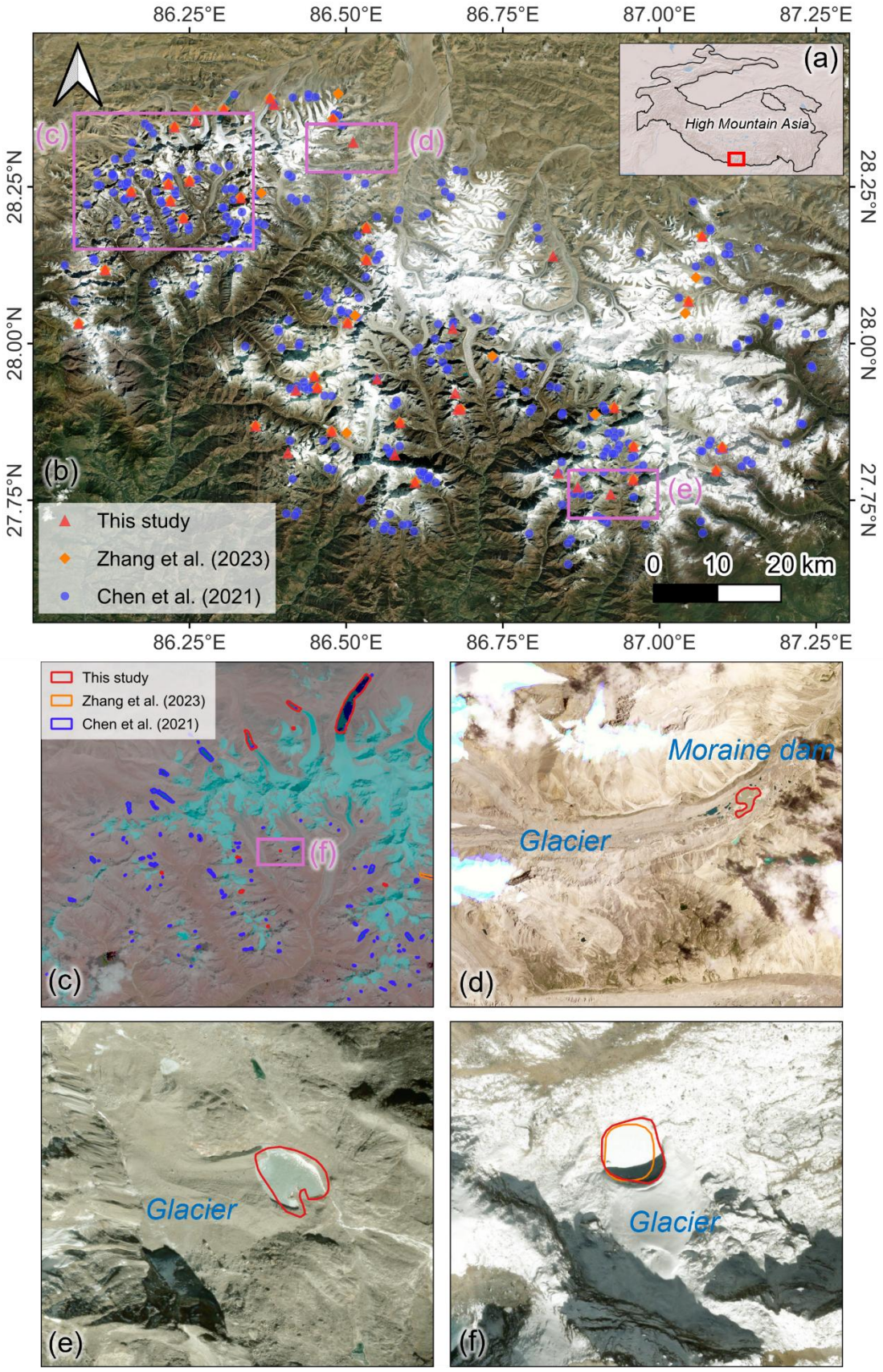

Figure S 1 (a) Location of the sample subregion. (b) Comparison between our inventory and other glacial-lake datasets. (c) Zoomed-in example showing that Chen et al. (2021) classified most lakes

located in front of glacier termini as proglacial lakes, without strictly requiring direct glacier-lake ice contact. (d) In our inventory, supraglacial ponds at the glacier front that have coalesced into a single water body are mapped as a proglacial lake, whereas the other two datasets label them as supraglacial lakes. (e-f) Examples where our mapping captures features omitted in previous datasets. Basemap in panels (a), (b), (e), and (f) is Powered by Esri. Panel (c) uses Sentinel-2 imagery acquired on 29 September 2022. Panel (d) uses PlanetScope imagery acquired on 12 August 2022.