Distribution of glacial lakes in Afghanistan and observed changes (1990–2015)

KUNJ GLACIER AND GLACIAL LAKE IN PANJSHIR, KABUL BASIN, AFGHANISTAN, IN AUGUST 2018 (PHOTO: MAHBOOBULLAH BARIZ/NWARA)

Background

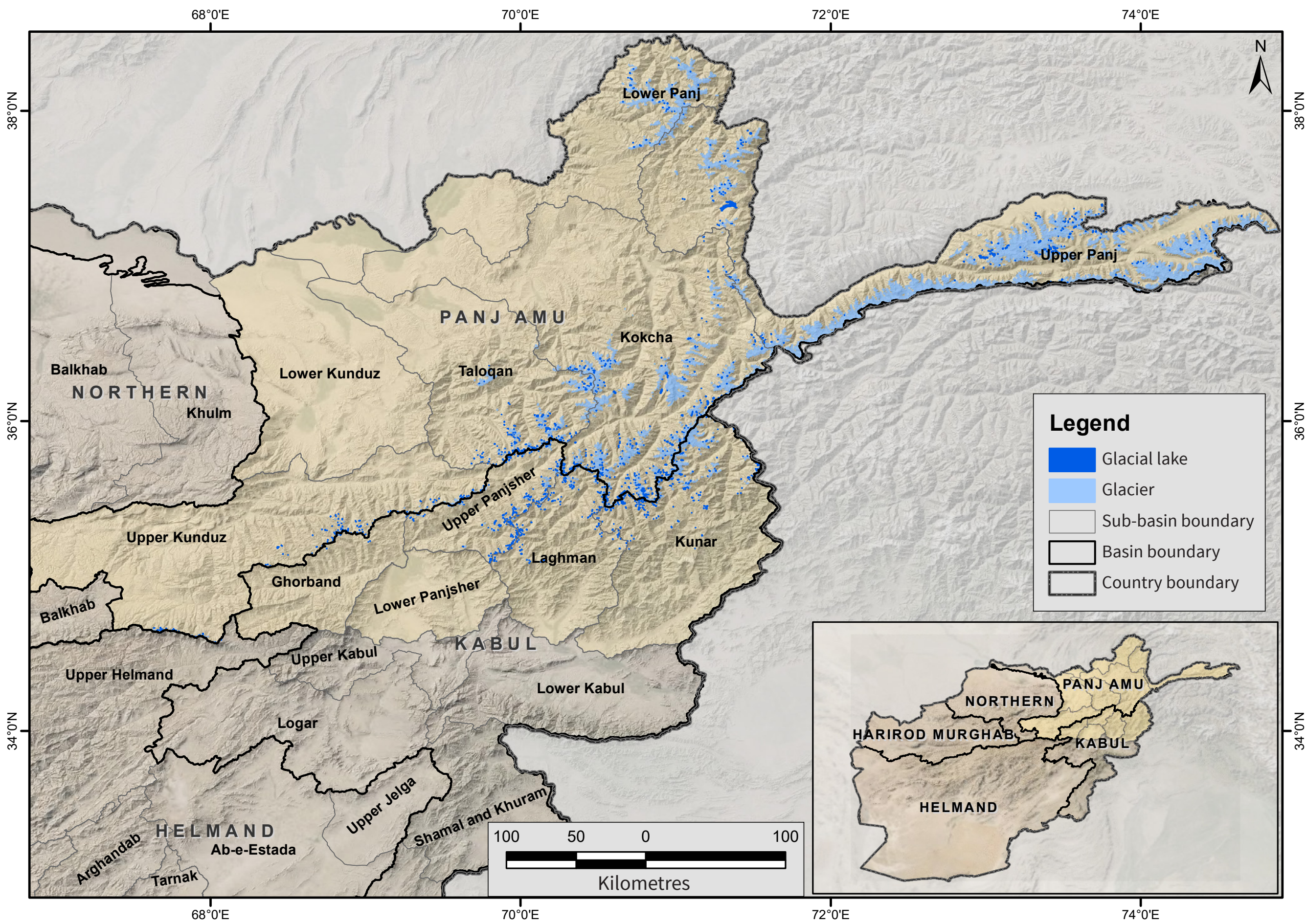
As glaciers move and flow, they erode the land surface beneath them, leaving depressions and grooves on the land surface. Melt water from glaciers fills up the hole, creating a glacial lake. Glacial lakes can also form from natural depressions that catch escaping melt water. Rapid rises in global temperature impact glacier retreat, and melt water often leads to the formation of new glacial lakes and expansion of existing glacial lakes. Too much meltwater from glaciers increases the pressure on glacial moraine barriers, which might cause a lake to overflow or burst, causing flooding. Also, various other factors like snow/ice or rock avalanches, debris flows and landslides, and melting of ice in moraines can impact glacial lakes and dams causing outburst floods. This phenomenon, generally known as a glacial lake outburst flood (GLOF), is one of the most serious disasters in the Hindu Kush Himalayan region.

During a needs assessment workshop carried out in Afghanistan in December 2015, the National Water Affairs Regulation Authority (NWARA) emphasized on the need for comprehensive data and information on glaciers and glacial lakes as a national priority. ICIMOD jointly works with NWARA through the SERVIR-HKH Initiative, a joint initiative of USAID and NASA, on developing information on glaciers and glacial lakes in Afghanistan. The glacier datasets (1990–2015) for Afghanistan were launched at a dissemination workshop organized at the Ministry of Energy and Water office (now NWARA) in Kabul on 2 July 2018. Thereafter, ICIMOD and NWARA's General Directorate of Water Resources have been working on developing information on glacial lakes in Afghanistan (Figure 1).

Methodology

Landsat images were used to map glacial lakes from 1990, 2000, 2010, and 2015. The methodology used to map glaciers in Afghanistan, i.e. semiautomatic object-based image classification, was also used to map glacial

FIGURE 1 DISTRIBUTION OF GLACIERS AND GLACIAL LAKES IN AFGHANISTAN



FACTS AND FIGURES

Afghanistan has 1,942 glacial lakes that cover an area of 88.8 km^2.

The glacial lakes mostly range from 0.003 km^2 to less than 1 km^2 in size. Only three lakes are larger than 1 km^2.

The largest lake (14.63 km^2) is located in the Upper Panj sub-basin.

The glacial lakes are found from 2,900 masl to 5,400 masl; 91% of the lakes are located between 4,000 and 5,000 masl.

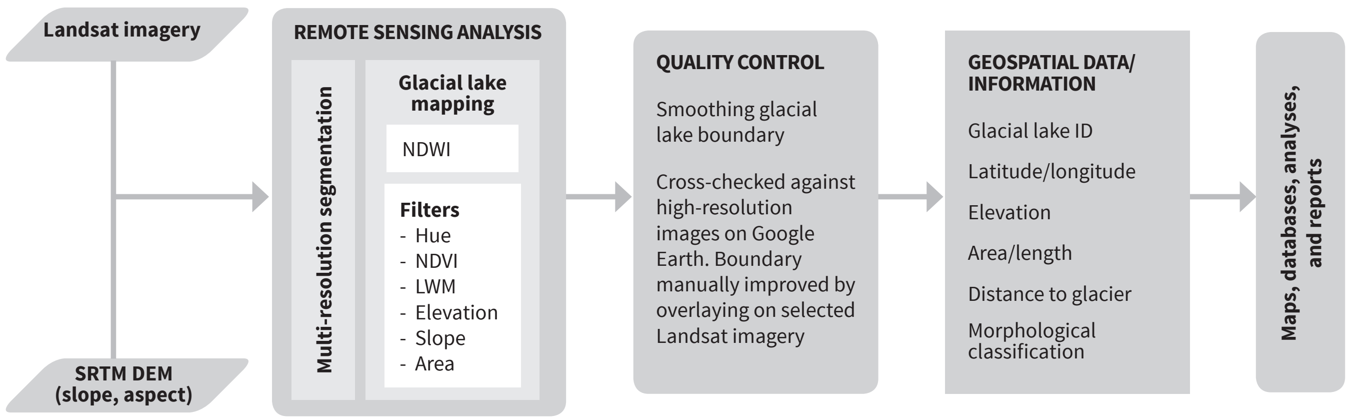
The Panj Amu basin contains the highest number (64%) and area coverage (74%) of glacial lakes in Afghanistan.

During a period of 25 years (1990–2015), the total number and area of glacial lakes in Afghanistan increased by 8% and 10%, respectively.

In recent periods, the formation of new glacial lakes and expansion of existing ones is higher than the disappearance and recession of glacial lakes.

lakes for consistency. Normalized difference water index (NDWI) [NDWI = (NIR-BLUE)/(NIR+BLUE)] was used as a primary index to categorize glacial lakes identified in the satellite images. Various filters – hue, normalized difference vegetation index (NDVI), and land and water mask (LWM) – were used to improve classification of glacial lakes misclassified as shadow areas resulting from spectral reflection, frozen lakes, fresh snow, and other land surfaces such as ice cliffs and walls of supra glacial lakes (Figure 2). The glacial lake polygons derived from automatic processes were further checked and refined manually by overlaying on Landsat imagery and cross checking against high-resolution satellite images available in Google Earth. Finally, the glacial lakes were classified into eight different types based on dam characteristics and morphological forms described in Maharjan et al. (2018). Other parameters were generated using the Shuttle Radar Topography Mission (SRTM) digital elevation model (DEM) and projecting the data in the World Geodetic System 1984 Universal Transverse Mercator projection. The glacial lake data for other periods (1990, 2000, and 2010) were prepared by manually correcting the 2015 lake data by draping over respective Landsat images.

FIGURE 2 METHODOLOGY OF GLACIAL LAKE MAPPING



Status of glacial lakes in Afghanistan (2015)

A total of 1,942 glacial lakes covering 88.8 km² were mapped from the Landsat images of 2015. Glacial lakes greater than or equal to 0.003 km² in size were considered for this inventory. These lakes are mostly concentrated in two river basins – Panj Amu and Kabul. Panj Amu basin has the highest number (64%) and area coverage (74% of total area) of the glacial lakes in Afghanistan (Figure 3 A).

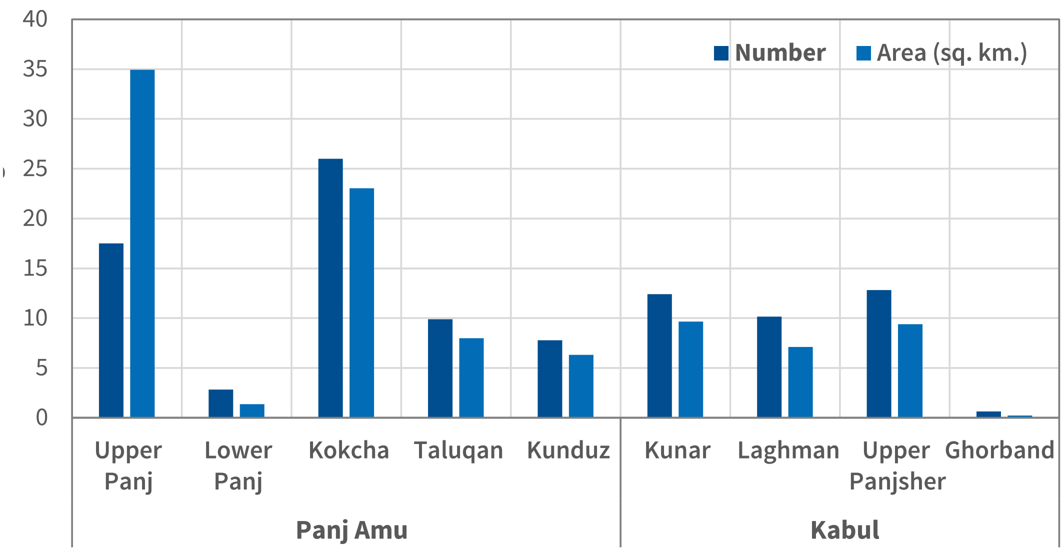
A majority of glacial lakes are bedrock dammed (72%), formed on depressed land surfaces including thin layers of moraine/debris resulting from glacier erosion. Moraine dammed lakes comprise about 22%, followed by other dammed lakes (less than 5%). Other dammed lakes are mostly blocked by landslides, debris flow, or alluvial flow on the glaciated valley. Only 1.7% of the lakes are ice-dammed lakes.

Glacial lakes less than 0.02 km² (Class 1) lakes are most common, contributing 52% of the total glacial lakes in the country. The number of glacial lakes decreases with an increasing size class of the lakes. However, Class 4 (0.1–<0.5 km²) lakes have the highest total area of glacial lakes (Figure 3 B). Only one lake was present in Class 7 (>=5km²) with an area of 14.63 km², which is the largest lake and is an other dammed lake (O).

Glacial lakes in Afghanistan are distributed from 2,900 to 5,400 masl. A majority of the lakes (91%) are located at elevation ranges from 4,000 to 5,000 with the highest concentration (61%) between 4,300 and 4,800 masl. Only three glacial lakes were mapped below 3,000 masl which are other dammed lakes. Lakes below 3,500 masl are mostly bedrock dammed or other dammed lakes. Moraine dammed and ice dammed lakes are mapped from 3,500– 5,300 masl and 4,000–5,400 masl, respectively (Figure 4).

FIGURE 3 (A) NUMBER AND AREA PERCENTAGE OF GLACIAL LAKES IN EACH SUB-BASIN OF AFGHANISTAN; (B) GLACIAL LAKE AREA SIZE CLASS VERSUS GLACIAL LAKE TYPES

(A)



(B)

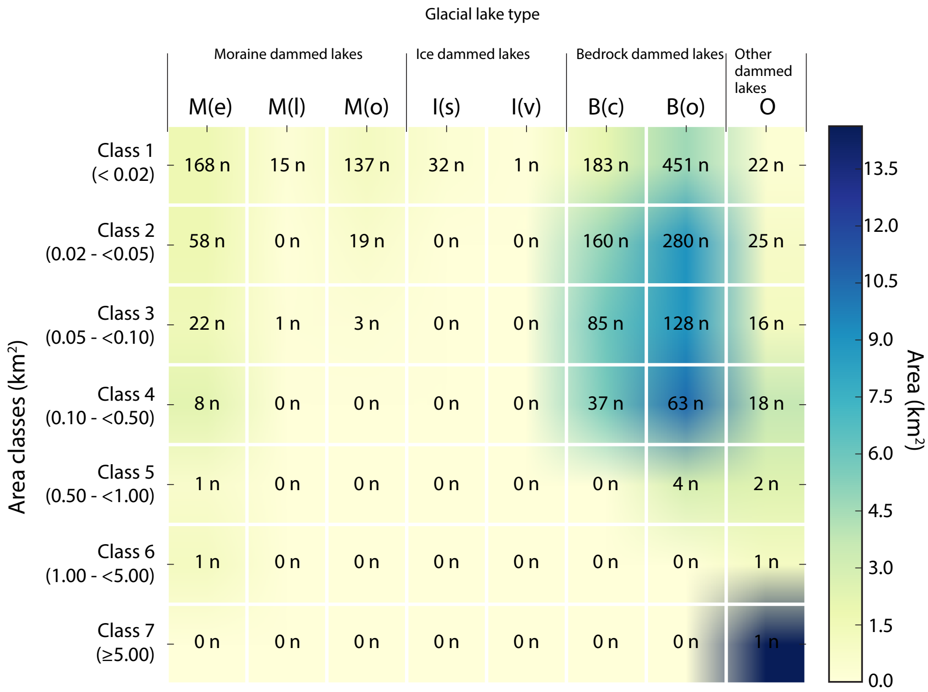
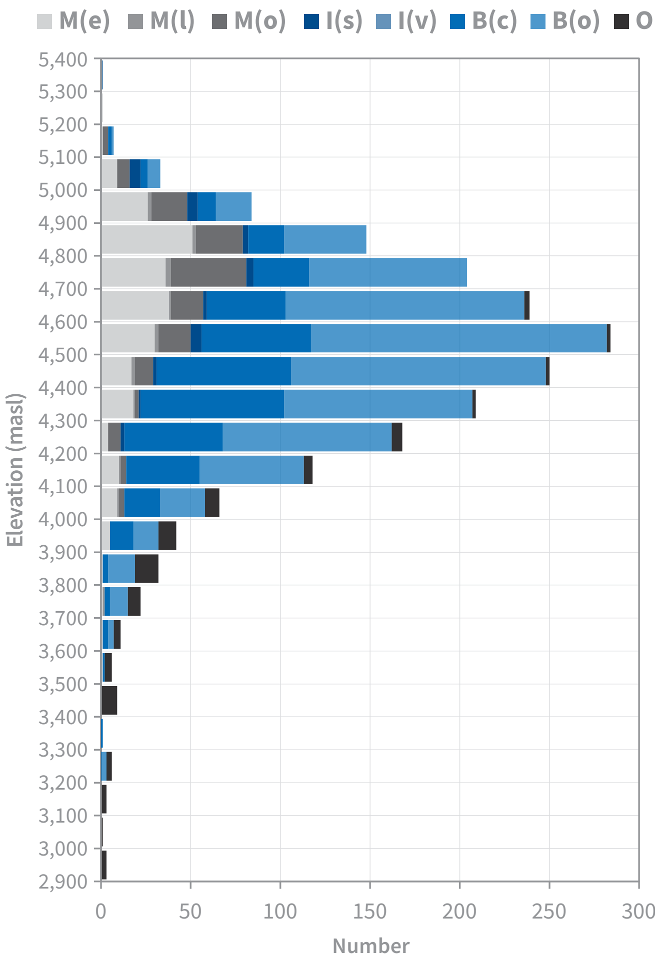


FIGURE 4 **DISTRIBUTION OF VARIOUS TYPES OF GLACIAL LAKES AT DIFFERENT ELEVATION ZONES**



Overall, more than 85% of the lakes are found within a distance of 5 km from glaciers in the country. Lake area coverage is also high within this distance. Almost 56% of the lakes are fed by glaciers. Lakes closer to glaciers (<5 km distance) are usually fed by glacial melt, whereas lakes that lie far ahead of glaciers may or may not be fed by glacial melt but instead are formed in paleo-glaciation landforms. Lakes closer to glaciers are mostly moraine dammed.

Spatio-temporal changes from 1990 to 2015

To assess and analyse glacial lake changes, a repeat glacial lake inventory of 1990, 2000, and 2010 was prepared.

In total, both the number and area of glacial lakes in Afghanistan show increasing trends by 8% and 10%, respectively, from 1990 to 2015 (Table 1). But the change rate varies between different periods, basins, and sub-basins. The percentage increase was very less through 1990 to 2000 compared with that in successive decades; higher increment rates were observed between 2010 and 2015. Also, varying change patterns were noticed in different basins and sub-basins at different periods. Overall, in 25 years, the number and area of glacial lakes have increased by more than 16% and 12.6%, respectively, in the Panj Amu basin. In the Kabul basin, the number of glacial lakes has decreased by 3.8% and the area has increased by 4.4%.

The change in numbers is higher in smaller-sized glacial lakes, whereas the change in area is higher in larger-sized glacial lakes, indicating the formation of new glacial lakes and expansion of existing glacial lakes. In various elevation zones, the formation and expansion of glacial

KUNJ GLACIER AND GLACIAL LAKE IN PANJSHIR, KABUL BASIN, AFGHANISTAN, IN JUNE 2019 (PHOTO: MAHBOOBULLAH BARIZ/NWARA)

TABLE 1 **DISTRIBUTION AND CHANGES OF GLACIAL LAKES IN EACH BASIN OF AFGHANISTAN FROM 1990 TO 2015**

Year		Panj Amu		Kabul		Afghanistan	
		Number	Area (km²)	Number	Area (km²)	Number	Area (km²)
1990		1,070	58.038	727	22.418	1,797	80.456
2000		1,164	60.189	729	22.526	1,893	82.715
2010		1,243	64.444	682	21.007	1,925	85.451
2015		1,243	65.385	699	23.413	1,942	88.798
1990–2000	Change	94	2.151	2	0.108	96	2.259
	Percent	0.088	0.037	0.003	0.005	0.053	0.028
2000–2010	Change	79	4.255	-47	-1.519	32	2.736
	Percent	6.79	7.07	-6.45	-6.74	1.69	3.31
2010–2015	Change	0	0.941	17	2.406	17	3.347
	Percent	0	1.46	2.493	11.453	0.883	3.917
1990–2015	Change	173	7.347	-28	0.995	145	8.342
	Percent	16.168	12.659	-3.851	4.438	8.069	10.368

lakes are very much dynamic and higher at elevation range from 4,000 to 5,000 masl. The number (70%) and area (55%) of the lakes have increased drastically at elevations from 4,500 to 5,000 masl in 25 years.

The emergence, disappearance, expansion, and recession of glacial lakes depend on the activity of glaciers, morphological conditions of glaciated valleys, and geometry of glacier and glacial lakes (Figure 6). The percentage of newly formed lakes is higher than disappeared lakes in all periods with a comparatively higher rate from 2010 to 2015 (Figure 5 A). Also, the expansion of existing glacial lakes is higher than the recession of glacial lakes in all periods and higher rates were observed for 2010–2015. The unchanged lake size is higher than other changed lakes in all periods, the rate of which has decreased in recent periods.

Out of 557 lakes that were recorded between 1990 and 2015, more than 55% of the lakes have growth rates less than 25% and almost 22% having growth rates between 25% and 50%. Nearly 10% of the lakes have growth rates between 50% and 75% and more than 3% have growth rates higher than 75% (Figure 5 B). These high growth rate glacial lakes are critical in terms of potential GLOFs and need further investigation and monitoring.

SHAH DARYABAR LAKE, PANJSHIR, AFGHANISTAN (PHOTO: ESMATULLAH JOYA, ICIMOD/NWARA)

FIGURE 5 (A) DISTRIBUTION OF FORMATION, EXPANSION, RECESSION, AND DISAPPEARANCE OF GLACIAL LAKES IN EACH TIME PERIOD; (B) NUMBER AND GROWTH RATE OF GLACIAL LAKES IN DIFFERENT TIME PERIODS

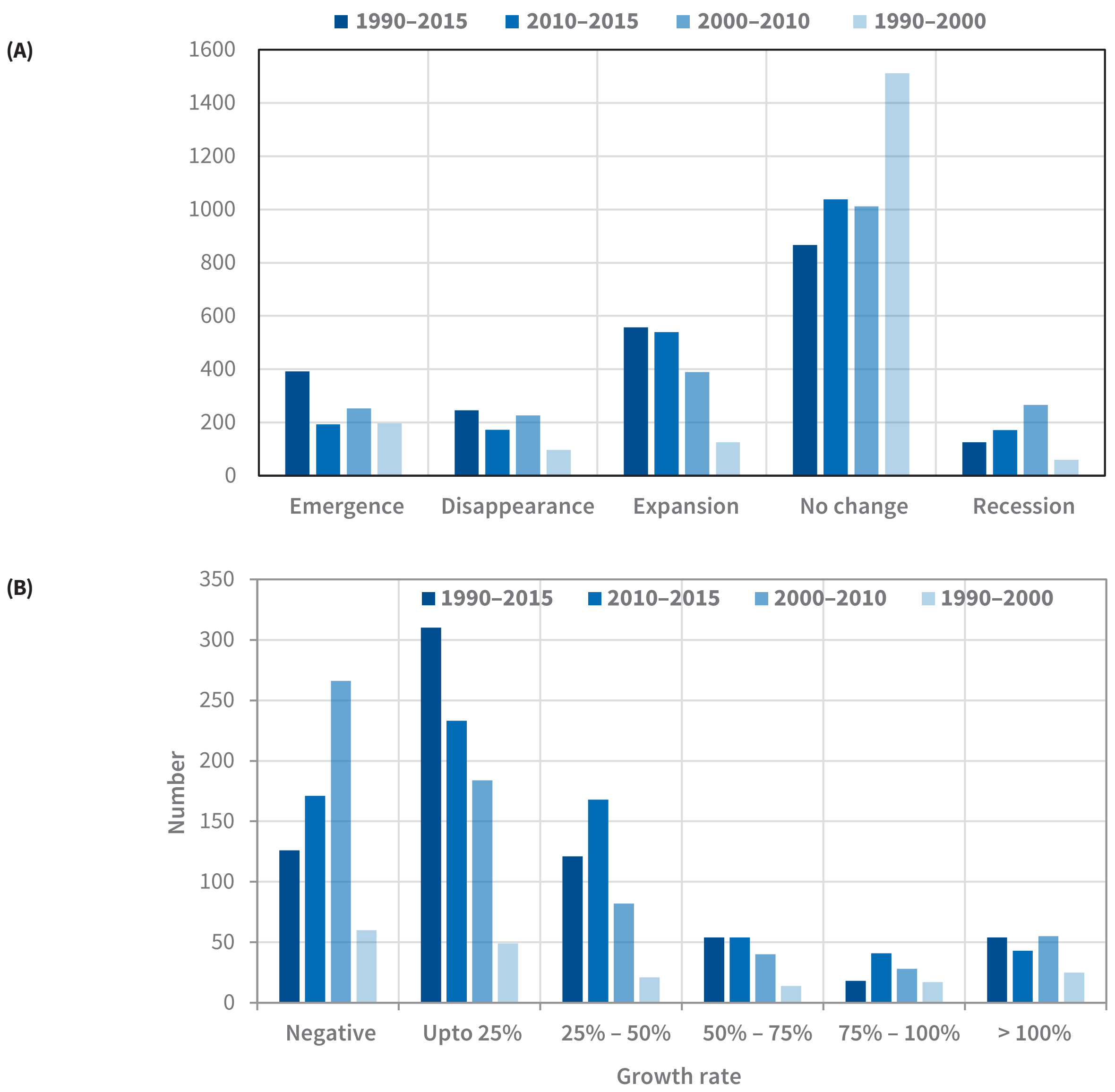
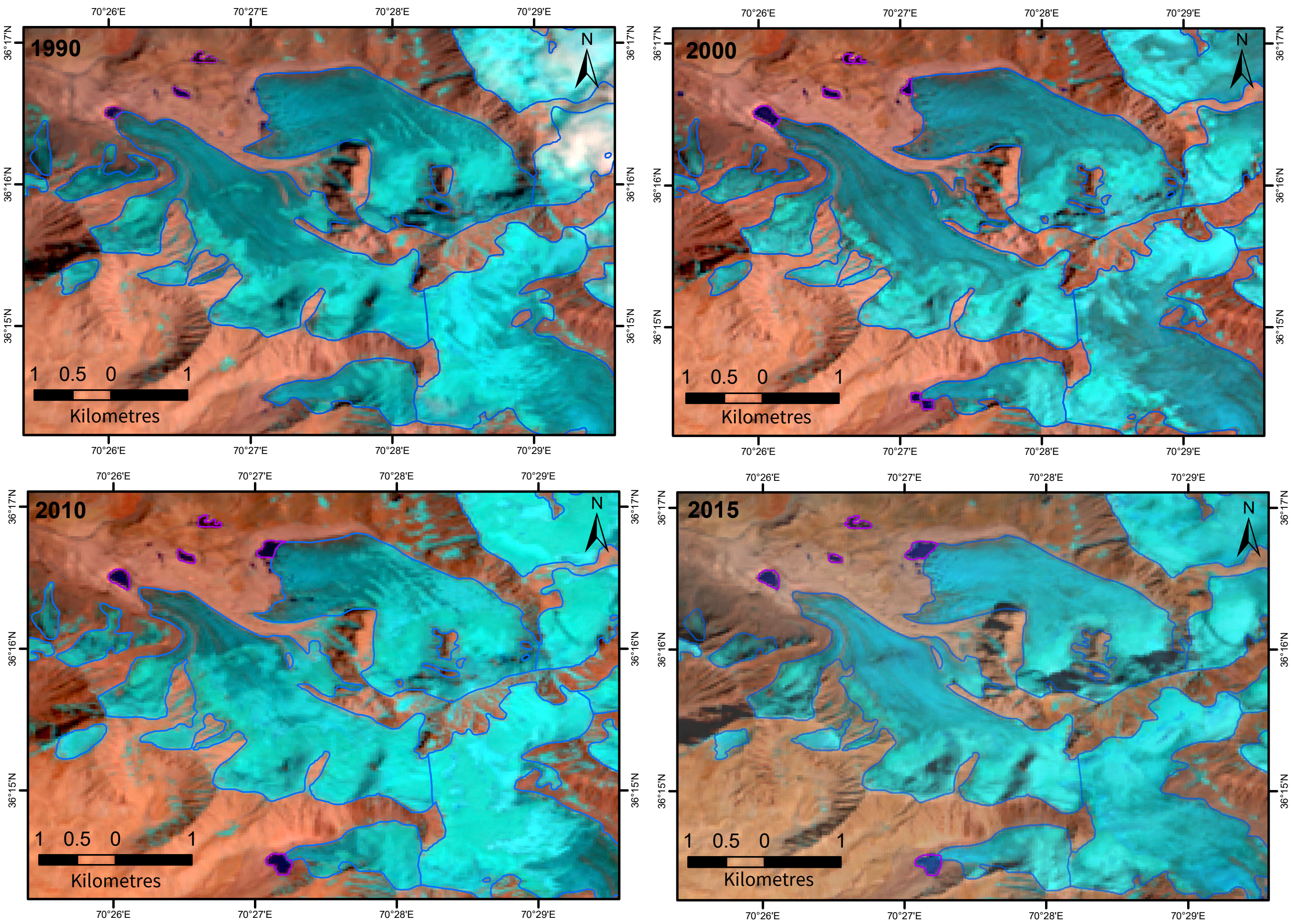


FIGURE 6 FORMATION AND EXPANSION OF GLACIAL LAKES IN TALOQAN SUB-BASIN OF PANJ AMU RIVER BASIN



Conclusion

Overall, the number and area of glacial lakes shows an increasing trend over the 25-year period (1990–2015), with a higher rate of increase during the second decade (2000-2010) and higher still in the last quinquennial (2010-2015). More new glacial lakes have formed than have disappeared, and more existing lakes have expanded than have receded. The rate of unchanged lakes has decreased in recent years, which indicates an increasing trend in the formation and expansion of lakes. This calls for systematic monitoring of these lakes. A detailed investigation should also be carried out to identify potentially dangerous glacial lakes to reduce the risk from GLOFs.

PREPARATION FOR GLACIER MASS BALANCE STAKE INSTALLATION IN PIR-YAKH GLACIER IN PARYAN DISTRICT, PANJSHIR PROVINCE, AFGHANISTAN (PHOTO: ESMATULLAH JOYA, ICIMOD/NWARA)

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DEBRIS-COVERED GLACIER AND GLACIAL LAKE NEAR THE PIR-YAKH GLACIER IN PANJSHIR VALLEY, AFGHANISTAN (PHOTO: ESMATULLAH JOYA, ICIMOD/NWARA)

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Research team
Sudan Bikash Maharjan, Finu Shrestha, Esmatullah Joya, Mohammad Murtaza Rahimi, Khan Agha Muazafary, and Mahboobullah Bariz

For further information
Birendra Bajracharya servirhkh@icimod.org
servir.icimod.org | **geoportal.icimod.org**

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