Thematic Focus: Climate change, Ecosystem Management

Measuring glacier change in the Himalayas

A serious lack of reliable and consistent data severely hampers scientific knowledge about the state of Himalayan glaciers. As a result, the contribution of glacial melt to the Himalayan river basins remains uncertain. This is of grave importance because declining water availability could threaten the food security of more than 70 million people. There is thus an urgent need to improve cross-boundary scientific collaboration and monitoring of glaciers to bridge the knowledge gap and allow policy options to be based on appropriate scientific evidence.


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Why is this important?

Seasonal meltwater from the Himalayan glaciers is one of the main sources of freshwater reserves that directly sustain people living in the region, especially in arid and semi-arid areas. At varying degrees and times, about 1.3 billion people living in the Himalayan river basins rely on both meltwater and monsoon waters to sustain their livelihoods, mainly for irrigation, drinking, sanitation and industrial uses *(9, 46, 33).* Net irrigation-water demand is high in this region (Table 1), but per capita water availability is very low — around 2 000 to 3 000 m^3/capita/year — which is far less than the world average of 8 549 m^3/capita/year) *(38).* Based on a projected estimate of

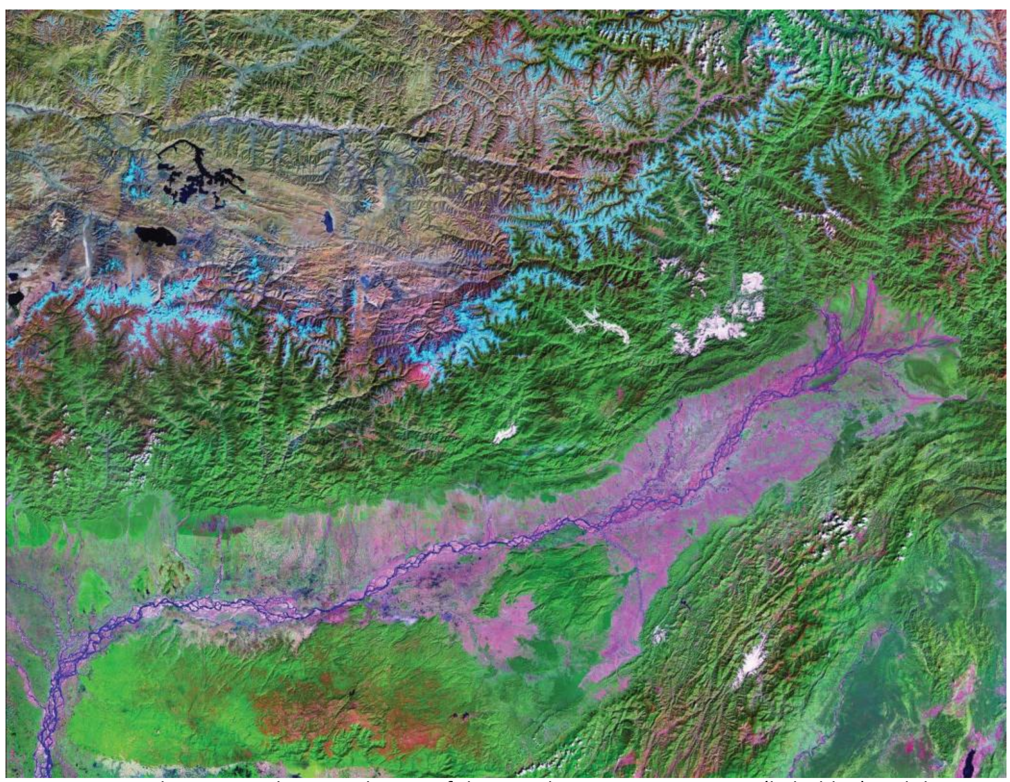


Figure 1: Landsat image showing glaciers of the Himalaya Mountain Range (light blue) and the sediment-choked and braided valley of the Brahmaputra River (purple) of Eastern India. High Resolution Image - 862KB (GN 2007).

glacier area in 2050, it is thought that declining water availability will eventually threaten some 70 million people with food insecurity (Table 1) *(17).*

The Hindu-Kush Himalayan region, including the Tibetan plateau, also functions as a complex interaction of "atmospheric, cryospheric, hydrological, geological and environmental processes that bear special significance for the Earth's biodiversity, climate and water cycles" *(48)*. For example, the region plays a prominent role in generating the Asian monsoon system that sustains one of the largest populations on earth *(5).* These ecosystem services from the Himalayan river basins also form the basis for a substantial portion of the region's total Gross Domestic Product (GDP) *(9).*

Parameter	Indus	Ganges	Brahmaputra	Yangtze	Yellow
Total population (millions)	209.619	477.937	62.421	586.006	152.718
Net irrigation water demand (mm/yr)	908	716	480	331	525
People threatened by food insecurity (millions)	26.3 ± 3.0	2.4 ± 0.2	34.5 ± 6.5	7.1 ± 1.3	
Percentage decrease in mean upstream water supply	8.4*	17.6	19.6	5.2	
Percentage increase in mean upstream rainfall	25	8	25	5	14

*Table 1: Based on a best guess of glacier area in 2050, this projection shows the number of people in the Himalayan area who could be threatened by food insecurity due to changes in the Himalayan glaciers. Increased mean upstream rainfall partly compensates for upstream water losses, although net irrigation demand may put more stress on the region's food security. The Yellow River basin, where there is an increase in upstream water yield, is an exception. The Yellow River basin only marginally depends on glacial melt; thus there is a notable 9.5 per cent increase in upstream water yield in the basin with an estimate of an increase of 3.0±0.6 million people that can be fed in the Yellow River basin. Upstream refers to the area above 2,000 m altitude. (17). * upper Indus*

Part of the water flow in these river basins depends on snow and glacial melt to perennial rivers, such as the Ganges, Indus, Brahmaputra, Mekong and Yangtze *(9)*. In turn, the amount of snow- and ice melt influences runoff into lowland rivers and the amounts of water recharging river-fed aquifers. The greatest dependence is in arid and semi-arid areas, such as western China, northeastern Afghanistan, Uzbekistan and parts of Pakistan *(17, 37)*.

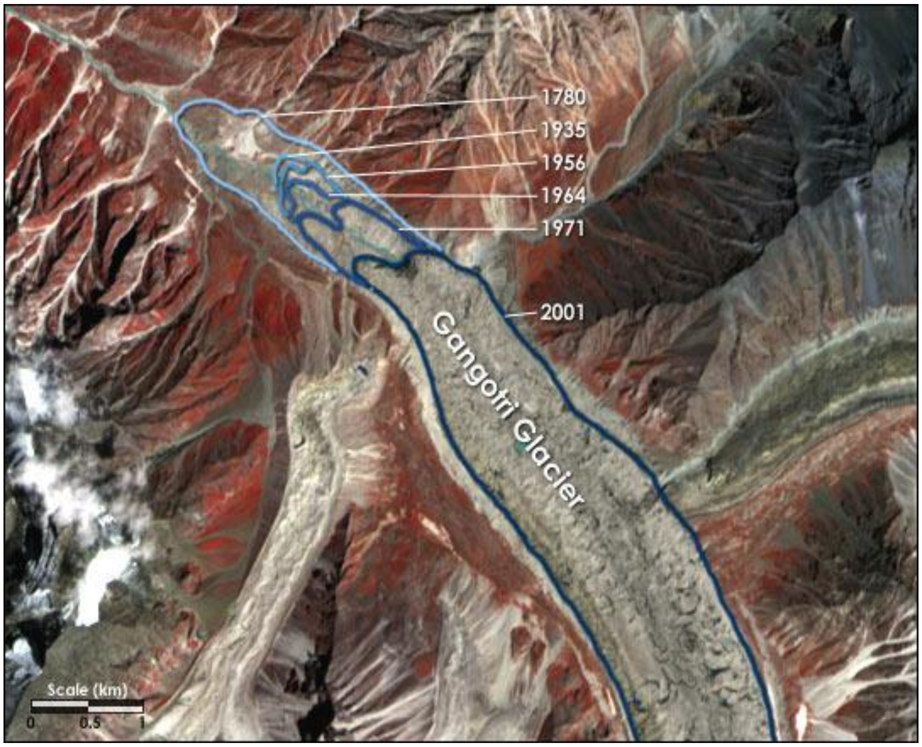
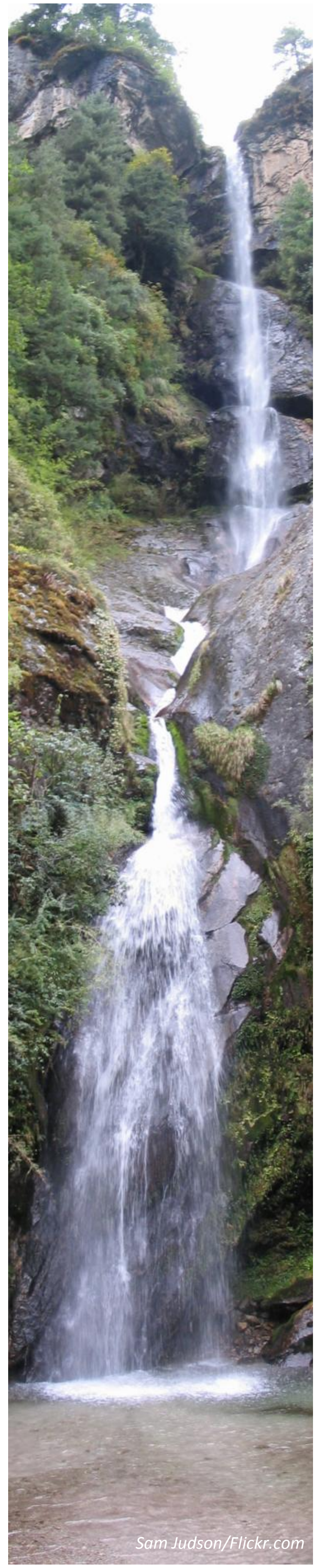


Figure 2: Gangotri Glacier, source of the Ganges, is one of the largest glaciers in the Himalayas. It has been receding since 1780 and in recent years the pace of retreat has accelerated. (Image from: NASA Earth Observatory, Jesse Allen).

In Western China, 25 per cent of the population directly depends on meltwater in the dry season (*47)*; there is less dependence in monsoon-dominated regions *(*8*)*.

Despite the key role meltwater plays in people's livelihoods and on the region's ecosystem services, such factors as annual amounts of ice and snow melt, its seasonal and spatial variability, as well as the contributions of precipitation to these basins, have not been clearly enumerated *(*24*)*.



The State of Knowledge

Are the glaciers retreating, and if so, is climate change the cause?

Many studies state that the melting of glaciers is a clear indicator of climate change *(46, 20)* and note that glacier change is the most visible and obvious indicator of changing temperatures *(*1*,* 43*)*. Temperatures at some locations in the Himalayan region have risen faster than the global average. From 1982 to 2006, the average annual mean temperature in the region increased by 1.5 °C with an average increase of .06 °C per year, although the rate of warming varies across seasons and ecoregions *(*34*)*. It stands to reason that the rising temperature in the Himalayas would affect glacier melt *(*3*)*. However, uncertainty about the current state of Himalayan glaciers *(*4*)* and the future state of the climate, as well as an incomplete understanding of the processes affecting Himalayan glaciers under the current climate, make any projections of climate change's impact on glaciers uncertain as well *(*2*,* 23*,* 17*, 39)*.

Issues related to Himalayan glaciers have become a major focus of public concern and scientific debate *(4)*. In spite of recent attempts to address the knowledge gaps on the state of Himalayan glaciers, the findings still show inconsistencies, as illustrated in the following examples:

- Analyses by Bolch and others (2012) and Gardelle and others (2012) have shown gains in the glaciers of the central Karakoram region (Figures 3) *(4,12)*, although the complex behaviour of the glaciers is still unclear;
- Jacob *and others* (2012) estimated glacial melt to be 4±20 Gigatons (Gt) per year for 2003-2010 *(22).* This amount is significantly lower than the estimate of 47±12 Gt per year for 2003-2009 by Matsuo and Heki (2010) in High Mountain Asia (HMA) *(27);* both studies used the Gravity Recovery and Climate Change Experiment (GRACE) (1 Gt water is equivalent to 1 km^3);
- Many glaciologists *(30)* remain skeptical about the GRACE results (above);
- Scherler and others (2011) report that 50 per cent of observed heavily debris-covered glaciers in the westerlies-influenced Karakoram region show advancing or stable conditions *(32)*;
- Contrary to the aforementioned report, a recent study by Gardelle and others (2012) reveals that high rates of ice loss can occur on debris-

covered glacier tongues (12). Similarly, Bolch and others (2012) noted that the debris-covered area has increased indicating negative mass balance (4).

Despite inconsistencies in the published research, there is overall agreement that scenarios indicate a general decrease in ice volumes in HMA *(23, 17)*. Widely-quoted findings from the entire region show that glacier retreats occurred mostly in the east *(4), (Figure 3), 1, 26, 15, 25)*, while in the west, the glaciers' responses are complex, especially around the Karakoram region. Since the 1990s, expansion of some larger glaciers has been observed in the central Karakoram *(18, 14)*; and some have advanced and thickened *(12, 32, 7)* indicating an apparently atypical climatic response *(23)*. The current behaviour of Karakoram glaciers prevents drawing conclusions about how the glaciers will continue to respond in the Karakoram region in the future *(28)*.

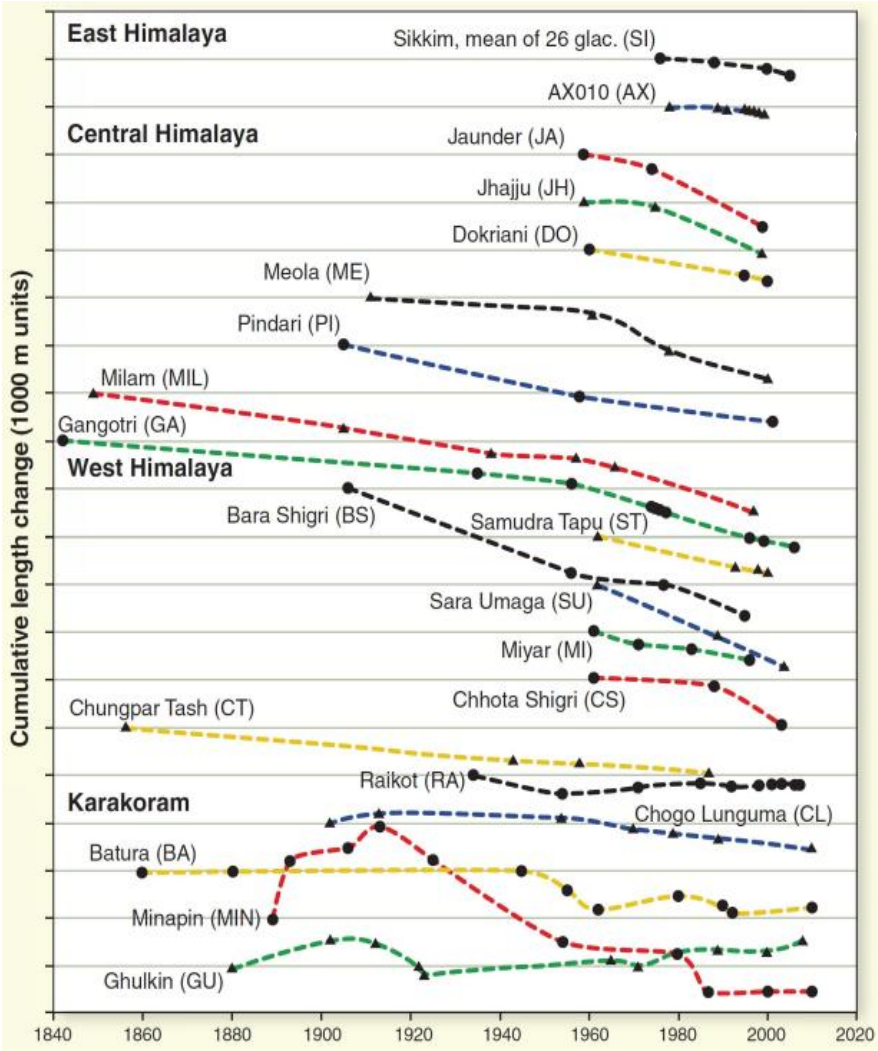


Figure 3: Most of the Himalayan glaciers show retreat since the mid-19th century, except the glaciers at Nanga Parbat in the northwest (RA, CL) and glaciers in the Karakoram, which show a complex behaviour (4).

The variability in trends across the entire Himalayan region is because accumulation and ablation patterns are distinctly uneven (Figure 4). For example, there is accelerated glacier wastage in humid environments but it is suppressed in arid ones *(10)*. Glaciers within the same climatic zone do not necessarily respond in a similar manner, and exhibit their own individual behaviour *(19)*. In addition, the environmental setting of the Karakoram is different from the eastern part of the Himalaya region (Figure 5). — it is colder and its latitude is up to ten degrees farther north than Nepal *(19)* (Figure 4). And the western Himalaya and Karakoram lie outside the region dominated by the Indian Monsoon.

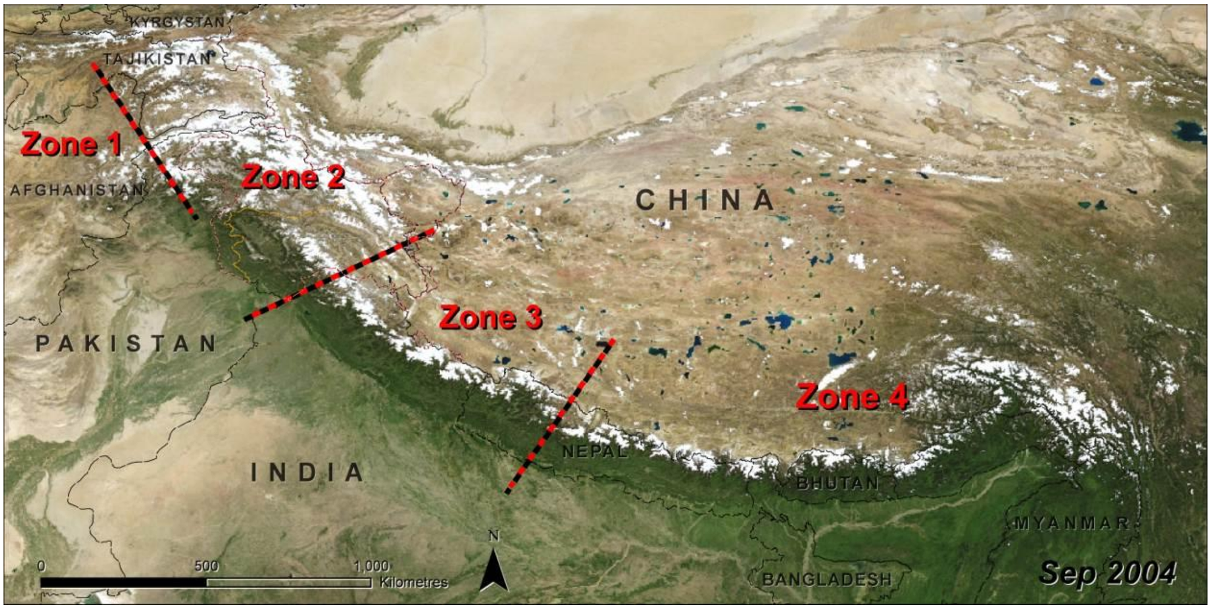


Figure 4: *While data are lacking for a good understanding of the patterns of change in the glaciers of the Himalayas, there are some generalizations that can be made about the different regions of this vast area.* ***Zone 1*** *– Mainly in Afghanistan, this area has relatively stable or very slowly retreating glaciers.* ***Zone 2****: The Northwestern Himalayas including the Karakoram have highly varied glacier behaviour, with many surge glaciers, many advancing, stable, and retreating snouts and comparatively few large lakes. Glaciers in the Pamir Mountains of Tajikistan are generally retreating while further south, behaviour of the Karakoram glaciers is mixed, but lacking wholesale, rapid disintegration of glacier tongues and rampant lake growth****. Zone 3:*** *Mainly in India, southwestern Tibet and western Nepal, this area has mainly stagnating, retreating snouts and time variability with periods of slower retreat for some glaciers during parts of the 20th and 21st centuries. There are fewer lakes than in the eastern Himalayas, but large lakes may be a growing phenomenon as glaciers thin and tend to stagnate.* ***Zone 4****: Mainly Nepal, Bhutan, Sikkim and southeastern Tibet, this area has many large glacier lakes, especially since the 1960s. Many glaciers are rapidly disintegrating as they stagnate and thin. Glaciers on the south side generally have more debris cover than they do on the north side (23). Background image from NASA Blue Marble MODIS data.*

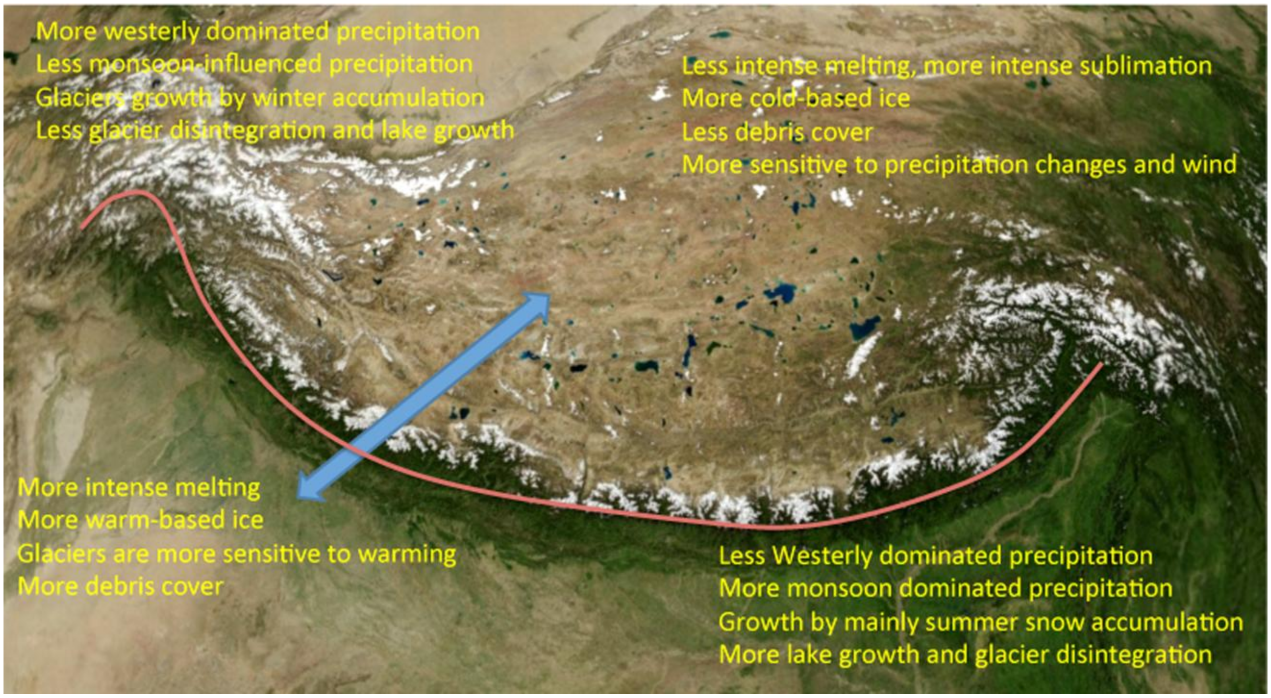


Figure 5: Climatic variations in the Himalaya region. The climate differs between the east and west and between the north and south, with variations in sources and type of precipitation and in glacier behaviour and dynamics. There is no sharp dividing line along the 2 000 km-long stretch between the east and west (1, 23). Background image from ESRI ArcGlobe 10.0.

Contribution of glaciers to hydrology in the Himalayan basins

There has been no long-term comprehensive in-situ monitoring of glacial melt contributing to the knowledge of hydrology in the river basins of the Himalayan region. As a result, studies on glacial melt that describe a basin's hydrology lack direct evidence and sometimes appear to be inconsistent (1, 24). This has led to a change in perception about the level of threat, and doubts have arisen that melting glaciers provide a key source of water in downstream areas across the entire Himalayan region. Earlier estimates are now thought to have been far too large and plagued by conflicting results and inadequate, highly qualitative or simply local-scale evidence. As a result, the situation has been downplayed more recently as the threat was seen to be less acute than foreseen earlier (1, *17*) (see Table 1). Kargel and others (2010) note that "glaciers are vitally important but widely exaggerated water resources" *(23).* The numbers of people affected were also downplayed as reports on the vulnerability of hundreds of millions or billions of people who depend directly on meltwater were revised to millions of people (23). Some studies, such as the following, even showed that flows into some basins are mostly driven by precipitation:

- Runoff due to glacial melt is minor in the wetter monsoon catchments of the Ganges and Brahmaputra but more substantial in the drier westerly-dominated headwaters of the Indus *(17 , 24)*;
- In glaciated regions with winter accumulation, where an earlier peak of spring snowmelt is expected, the monsoon-influenced catchments will maintain peak discharge in summer even with significant reduction in glacier size *(17 , 24)*;
- Inter-annual runoff variation in the Himalayan glacier catchment is driven more by precipitation than by the mass balance change of glaciers *(36)*;
- In the Dokriani glacier, winter snowfall has a more pronounced effect on headwater runoff variability than the variation produced by runoff from a receding glacier *(37)*.

In addition, a widely cited estimate shows considerable variation in the contribution of meltwater across the river basins fed by Himalayan glaciers *(9, 44)* (Figure 6), although this varies seasonally and spatially. The importance of meltwater contribution also varies by basin: it is extremely important to the Indus basin, important for the Brahmaputra basin, but plays modest roles for the Ganges, Yangtze and Yellow Rivers *(17)*. By region, meltwater contributes 30 per cent to the total water flow in the eastern Himalayas, 50 per cent in the central and western Himalayas and 80 per cent in Karakoram *(46)*. Likewise, Rees and Collins (2006) show that if all the Himalayan glaciers were to disappear, there would be about a 33 per cent reduction in annual mean flow in the west compared to the 1990 level, whereas the decline in the east would be only about 4-18 per cent *(31).*

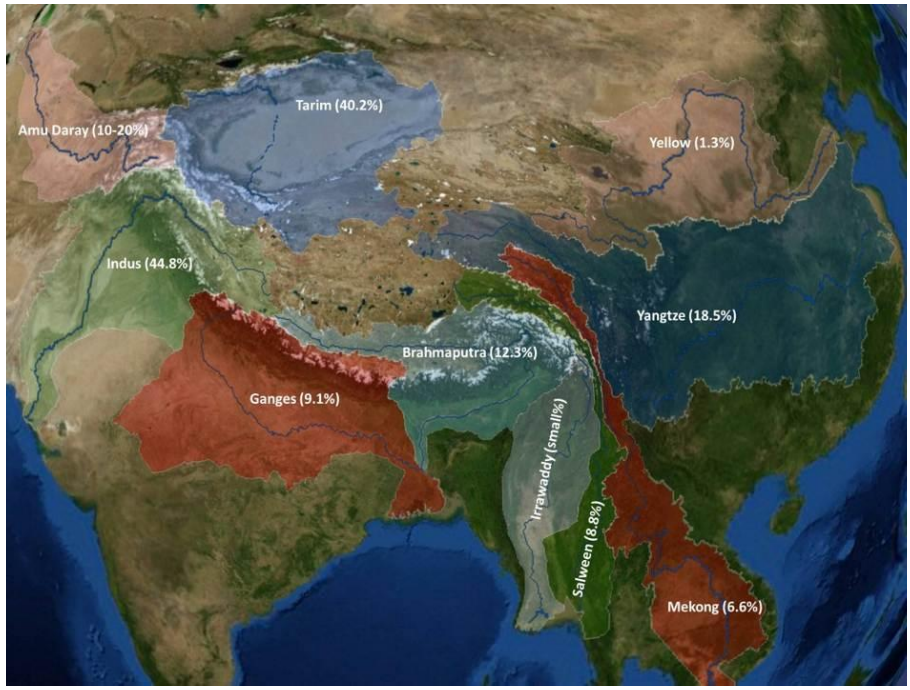


Figure 6: Predicted percentage of glacial melts contributing to basin flows in the Himalayan basins (Source: predicted percentage flow data from Xu and others 2008 (44). Shape files superimposed on background image from ESRI ArcGlobe 10.0).

What are the implications?

Scientific assessments and appropriate policy action remain problematic due to significant uncertainties on glacier changes in the Himalayas. However, available data suggest that the Indus and Brahmaputra Rivers are most susceptible to flow reductions due to the extent to which climate change is predicted to affect water availability; in turn, this threatens food security in those regions (Table 1) *(17).* For example, the Indus River, which has one of the world’s largest irrigation networks, is Pakistan’s primary source of freshwater and can been seen as its lifeline. About 90 per cent of Pakistan’s agriculture depends on the river and much of the world’s cotton comes from the Indus River Valley. On average, about 737 billion gallons of water are being withdrawn from the Indus River annually to grow cotton (enough water to supply Delhi residents for more than two years). In addition, the river is used for hydropower generation in Pakistan and India. Glacial melt contributes as much as half of the region’s flow *(41, 42)*. Also, meltwater is crucial for upstream reservoirs to store and release water to downstream areas when most needed. The Indus Basin Irrigation System gets its water supply from the Tarbela dam on the Indus River and the Mangla dam on the Jhelum River, both of which are located in the upper Indus basin and are fed largely by glacier meltwater. This shows that any change in the discharge from melting glaciers will have a considerable effect on the millions of people living downstream *(17)*.

An urgent need for appropriate monitoring

The scientific quality of assessments on the state and trends of Himalayan glaciers relies to a large extent on the availability of an adequate coverage of long-term and comprehensive data *(1)*. Data and information on Himalayan glaciers, however, are sparse and lack consistency, multi-temporal recording and field-validation; thus, rates of change for the entire region are unknown *(23, 6)*. The region has been known as a “white spot”, a term used in the IPCC 2007 Assessment Report to refer to an area for which there are “little to no data” *(40)*. The IPCC reports also note an urgent need for more information, especially about water use, the role of altered flow regimes and changes in ice cover, which have been less studied than temperature effects *(20)*. Also, total glacier behaviour is not systematically monitored. For example, the complex flow dynamics of glaciers is not yet fully understood, due in large part to their physical complexity and spatial diversity. The focus has often been on the influence of climate on glaciers to the neglect of ice dynamics *(1)*. Predicting the behaviour of glaciers is further complicated when they terminate in glacial melt lakes such as these in Bhutan (Figure 7).

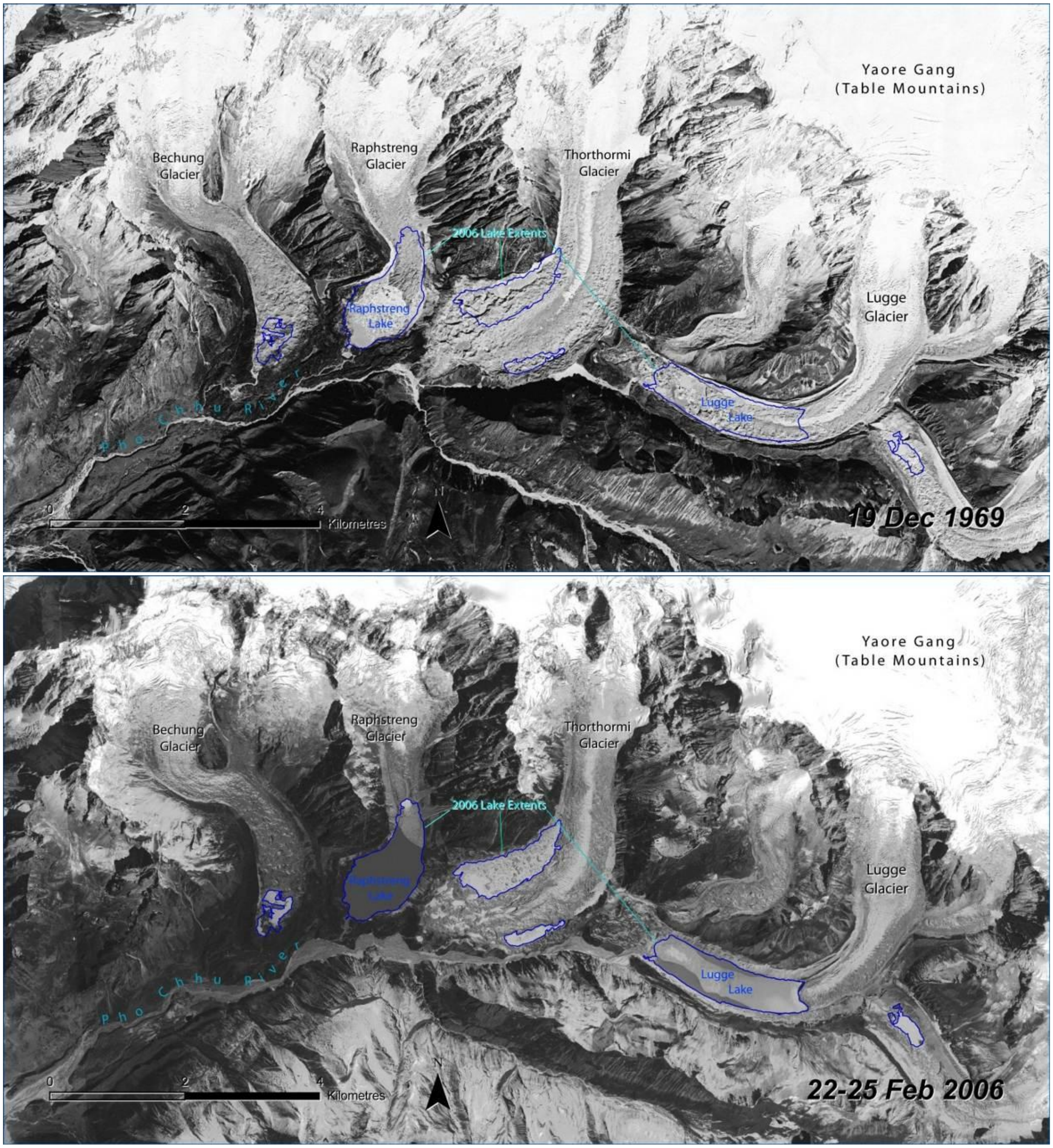


Figure 7: The water can float the terminus releasing it from the resistance of the land surface and accelerating its flow. The feedback of increased lake levels on the flow rate can create a positive feedback loop. Rising water levels in glacial lakes can lead to catastrophic floods. The Lunana area shown above has experienced several such disasters in the past 50 years (21).

This has constrained in-depth investigation of vulnerability and adaptation to climate change, which have become central to climate science and policy *(35)*. This is especially the case in attempts to understand the food, water and energy security implications for the people living in the basins who depend directly on meltwater, either seasonally or as an overall component of their water budget, and how they are affected by climate change in their mountainous environment *(13)*.

Although monitoring coverage of Himalayan glaciers is improving, it is not yet sufficient to fill the knowledge gaps. There are still constraints, such as variable retreat rates, poor glacier mass-balance data *(32)* and a lack of systematic long-term in-situ measurement *(11)*. In addition, available data are not always accessible, especially on transboundary water sharing, often for reasons "that concern politics and diplomacy rather than science" *(29)*. Available measurements mostly come from easily accessible glaciers at lower elevations *(1)*; (also see Figure 8 and 9). Out of an estimated 12 000 to 15 000 glaciers in the Himalaya range alone, only a very few have adequate mass-balance data *(4, 1)*. Thus, experts have recognized the need for greatly increased long-term measurements of glacier mass balance in the region to build a reliable understanding of the more important long-term trend *(23, 1, 39)*.

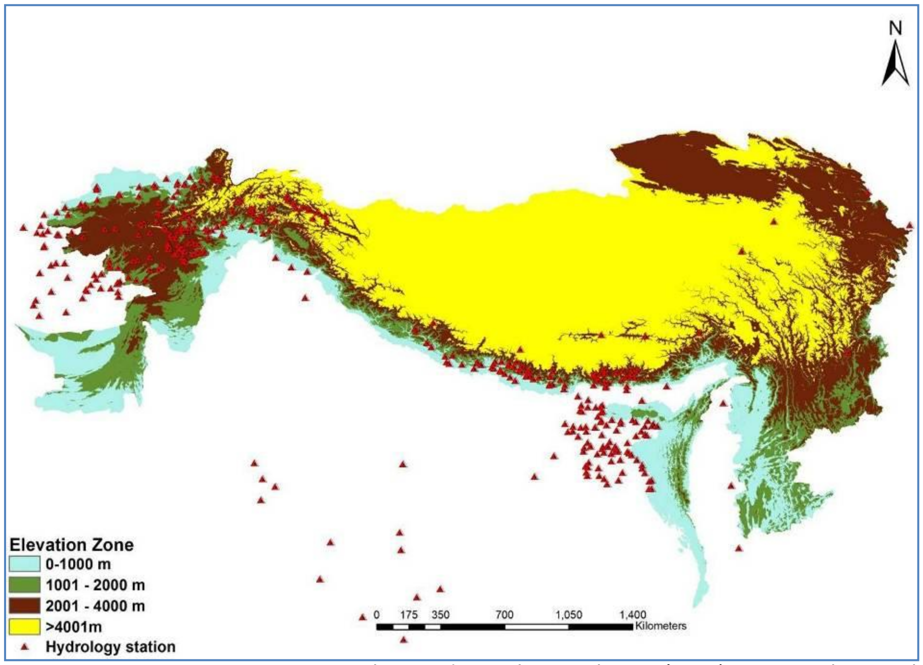


Figure 8: Monitoring stations in the Hindu-Kush Himalayan (HKH) region. The World Glacier Monitoring Service record shows only 97 monitoring stations in the HKH region in May 2011 (16).

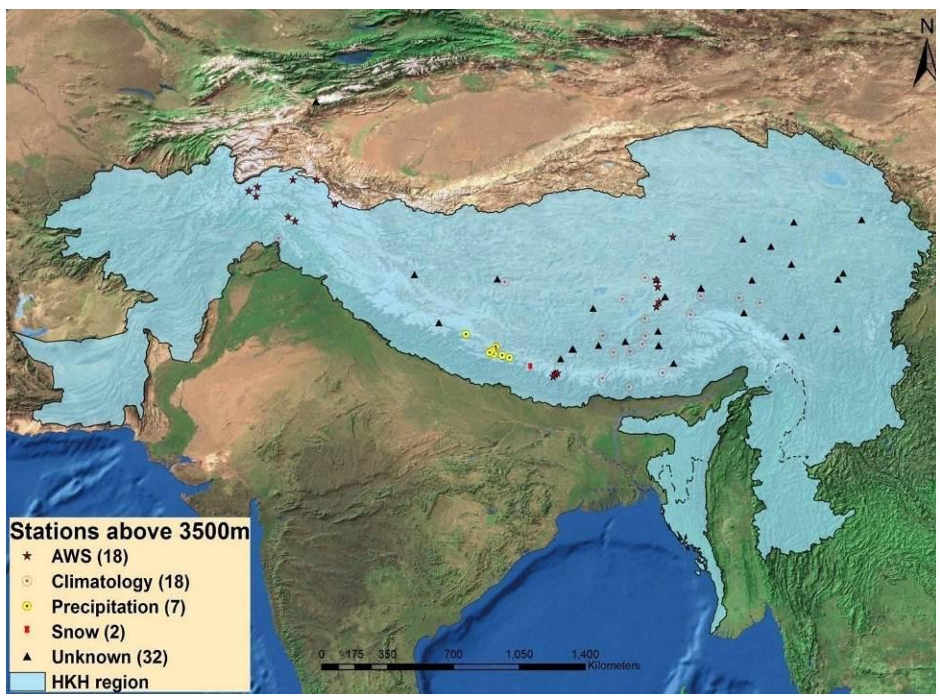


Figure 9: Monitoring stations above 3 500m in HKH region; there are only two snow monitoring stations (16).

Remaining challenges for the Himalayan region

This report shows that scientific studies and evidence are currently inadequate to assess the status and trends of Himalayan glaciers. This in turn, hampers the development of future projections on likely impacts on both people and ecosystems, and hinders effective action to adapt to anticipated changes in the Himalayan region.

This report also notes that a greater focus on glacier assessments in the Himalayas appears to have led to a tendency to ignore policy-relevant information because of its uncertainty. Hence, effective communication between the scientific community and policymakers is urgently needed to relay available knowledge about the potential impacts of changes in glaciers on the region's hydrology and environment and on the livelihoods of millions of people. More importantly, there is a need to communicate associated knowledge gaps in a clear and useful way, thus resulting in better decision making.

The region needs more and better monitoring of glaciers and subsequently a state-of-the-science assessment on glacier change that produces robust scientific findings to better understand the complexities of those changes and to reduce scientific uncertainty. In particular, transboundary scientific cooperation is needed to accurately assess regional climate change impacts on Himalayan glaciers and to fill knowledge gaps by providing scientific findings to the policy community based on the best scientific understanding of the issues *(48, 44, 45)*.

Acknowledgement

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