Shrinking glaciers in Bhutan

By Alex Hyde

The sub-tropical glaciers of Bhutan

Bhutan is a small mountainous nation located in the Eastern Himalaya, with a population of around 727 000 people (Figure 1). The country has a sub-tropical climate in its south, where it borders lowland plains, and a Himalayan subalpine climate to the north where it meets the Tibetan plateau and elevations reach as high as 7500 m above sea level. Glaciation in this region covers around 1500 km^2 with a volume close to 150 km^3 [1-2].

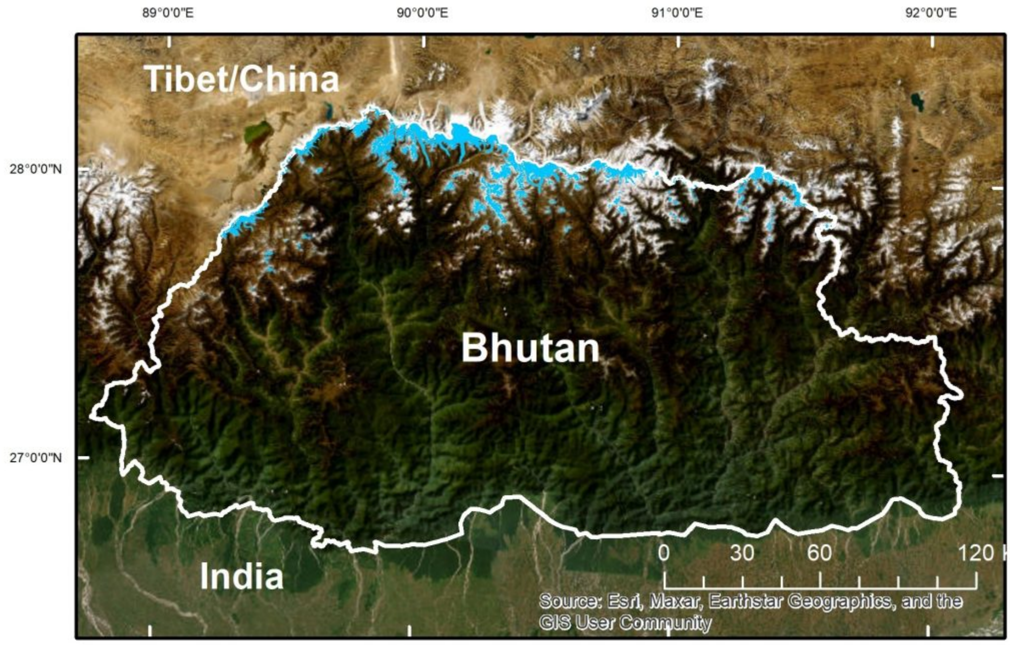

Figure 1: Map of Bhutan, blue regions in the north show glacier coverage. Credit: Alex Hyde.

Clean and debris-covered glaciers

Glaciers vary widely in morphology from numerous small-debris free cirque glaciers such as Gangrinchemzoe (Figure 2), to long debris-covered valley glaciers such as Tshojo (Figure 3); 13% of glaciers in the region are considered debris-covered [1].

Figure 2: Gangrinchemzoe, a small debris-free glacier with a glacial lake at 5200m (source: Glaciers of Bhutan2), https://pubs.usgs.gov/pp/p1386f/pdf/F7_Bhutan.pdf

Figure 3. Tshojo, a 11km long debris covered glacier in the Lunana region, fed by numerous smaller glaciers. Planet 2023. https://www.planet.com/explorer/

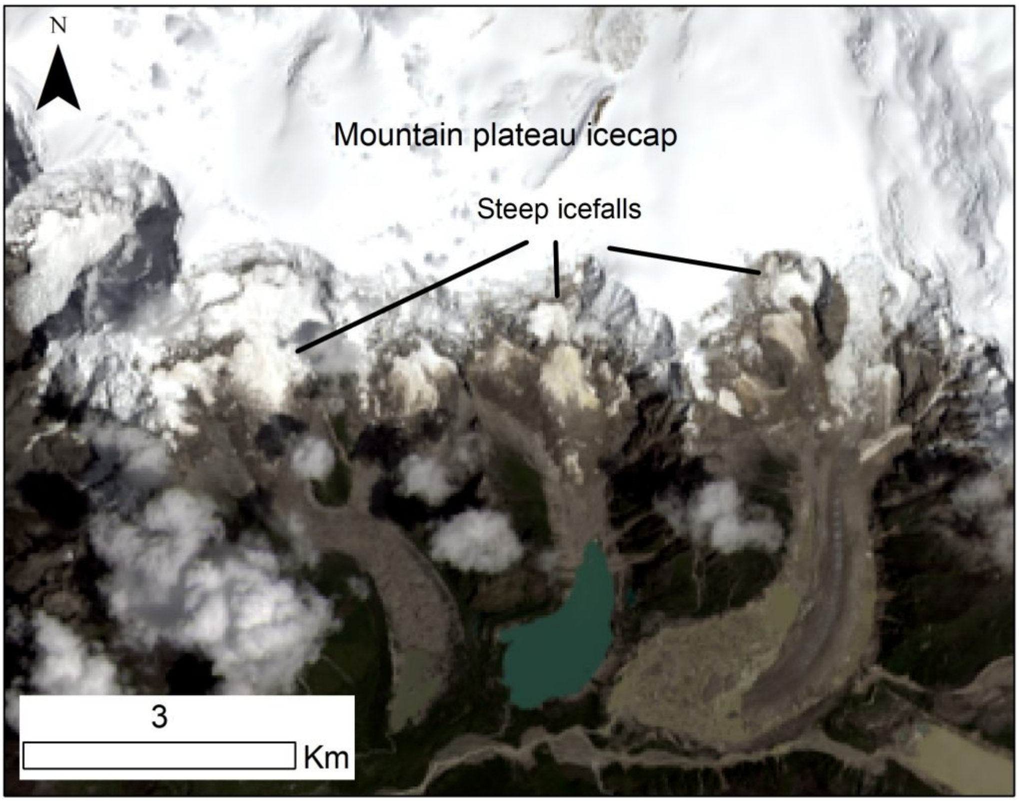

Figure 4. Plateau icecaps at 6500m feed large valley glaciers via steep ice falls in the Lunana region. Planet 2023.

Along the Himalayan divide we can also find a number of small ice caps that sit on high plateaus, feeding valley glaciers via steep ice falls (Figure 4).

Monsoonal accumulation

Glaciers receive much of their accumulation in the summer months in the form of monsoonal precipitation. 72% of the annual precipitation is received between June-September, fed by warm moist air moving up from the sub-continent.

In contrast, winters are typically dry and cool, with air moving down from Tibet [3].

Such 'summer-accumulation' type glaciers are highly sensitive to climate change, as warmer summer temperatures will mean that an increasing proportion of summer precipitation may fall as rain rather than snow, contributing to glacial ablation [1]. As such, the mean equilibrium line (i.e. the altitudinal dividing line between melt and accumulation) for all glaciers in Bhutan is relatively high; at around 5200 – 5300 m [4].

Glacier-meltwater resources

The majority of the population of Bhutan live alongside rivers supplied by melt from these glaciers, and therefore are dependent on the continuous water supply that this natural water tower provides, particularly in times of drought [5-7].

The glaciers act as a hydrological buffer for the supply of water against the strong seasonal variations in precipitation driven by the monsoon [8]. This therefore ensures reliable water supply during the dry winter season, important for both irrigation and drinking water, as well as hydroelectric power generation, which accounts for 99% of the country's energy supply (Figure 5).

Figure 5. Mangdechhu Hydroelectric Project is one of the most recent dams to be constructed in Bhutan, opened in 2016. The Bhtanese 2023. https://thebhutanese.bt/mangdechu-aims-to-restore-3rd-unit-by-july-end-to-cap-loss-at-1-2-bn-instead-of-1-8-bn/

Hydropower is also an important sector of the economy as much of the power generated is exported to neighbouring India, besides powering the countries profitable crypto industry [(9)]. Glaciers are therefore a vital natural asset to the Bhutanese economy, and the viability of future hydropower supply depends how it’s glaciers will respond to a changing climate.

Shrinking Glaciers of Bhutan

Climate change is driving reducing glacier volume in Bhutan. Warmer temperatures and increasingly variable seasonal precipitation patterns, including a delayed monsoon, as well as increasing spatial variability in where precipitation ends falls [(10)], has led to glacier shrinkage in the region.

Rates of glacier mass loss in Bhutan are nearly twice as high as in central Himalayan regions, and slightly higher than in Himachal Pradesh/Uttarakand and Western Nepal [(11-12)].

Mass balance, in meters of water equivalent (m w.e.), has become increasingly negative, decreasing from -0.20 ±0.08 m w.e. yr^{-1} (1974 – 2000), to -0.43 ±0.12 m w.e. yr^{-1} (2000 – 2015), this change is significantly higher than the Himalayan mean [(11)].

Influence of glacier lakes

Much of this variability may be explained by the presence of proglacial lakes; 22% of glaciers in Bhutan are lake terminating, up from 14% in 2000 (King et al., 2019), with rates of lake growth projected to continue increasing in this region, forming in the depression left by retreating glaciers behind the terminal moraine (Figure 6.) [(13-14)].

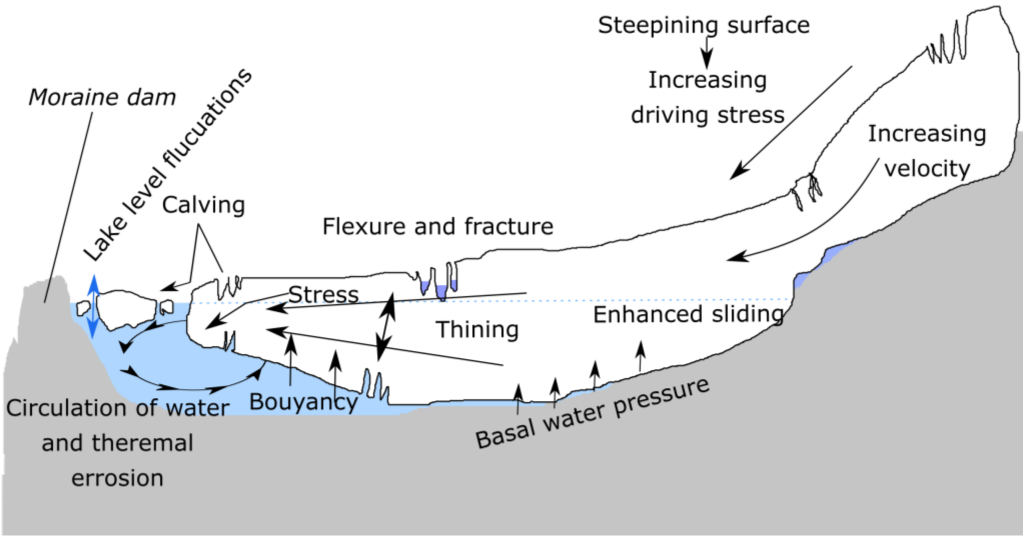

Figure 6. An illustration of the decoupling effect of glacial lake formation on glacier dynamics and energy balance. Credit: Alex Hyde

These lakes accelerate glacier retreat by raising the water temperature at the terminus, enhancing basal melt, while also increasing the water pressure at the glacier bed, resulting in increased velocities at the glacier terminus and therefore transfer of mass down glacier [15].

Forecasts for future glacier changes raise concerns; climate scientists expect to see increased precipitation in Bhutan under a warmer climate, but mass balance modelling has found that under a 2.5°C warming scenario we would see a >50% reduction in the glacierised area. This would lead to a >90% reduction in meltwater supply [16].

Hazards associated with glacier shrinkage

Not only will warmer temperatures because of climate change steadily drive a reduction in meltwater supply over the coming century, glacial retreat and resulting proglacial lake formation has also been shown to increase the risk of glacial hazards, particularly Glacial Lake Outburst Floods or “GLOFs” [17-18].

GLOF events in the Himalayas are typically triggered by a landslide or avalanche into the lake, leading to a lake dam collapse/overtopping, or erosion/melting of the dam leading to structural failure suddenly releasing the water [19].

Historic GLOFs in the Himalayas have had catastrophic impacts on downstream communities and infrastructure, with 15 million people exposed globally [17, 20-21]. Bhutan has seen 18 GLOF events in the last 70 years, the most recent occurring in 2019 from Thorthormi glacier Lake (Figure7) [19].

Figure 7. The large Thorthormi glacier and lake poses a significant flood risk to downstream communities (Source: The Third Pole)

In Bhutan, GLOFs are considered one of the primary risks from climate change, and the increasing number of glacial lakes, as well as degradation of permafrost resulting in more landslides may further increase GLOF risk in the future.

Adaptation and Mitigation

Figure 8. An early warning system put in place to rapid detect changes to river or lake levels (Source: WWF)

Strategies to mitigate such risk and adapt to long-term changes to water supply are of high priority in Bhutan. Flood warning systems are being developed to give early warning to downstream communities to allow for evacuation of flood risk areas (Figure 8) [22].

Alongside this, engineering strategies can be employed to drain water from glacial lakes, artificially lowered them to reduce the hydrostatic pressure on a moraine dam and limit the volume of water that can flood down valley (Figure 9) [23].

The estimated implications of climate change and its effect on future meltwater supply, are however stark and difficult to mitigate against. Some of this reduction in glacier volume may be replaced in the form of networks of reservoirs, however the most serious climate implications will only be avoided through concerted action on emission reduction [24].

Figure 9. Lake lowering works at the dangerous Thorthormi lake were conducted by the Bhutanese government between 2008 – 2012 (Source: WWF)

Further Reading

- Measuring glacier velocity (in Bhutan)
- GLOFS
- Glacier mass balance
- Glacier accumulation and ablation
- **Impact of climate change on Bhutan:** https://cdkn.org/sites/default/files/files/CDKN-IPCC-Whats-in-it-for-South-Asia-AR5.pdf
- **Glacial Outburst Flood Risks and adaptation strategies:** https://wwf.fi/app/uploads/h/5/7/5rqxrm5dl5ejasicpp5m4zc/the_cost_of_climate_change.pdf
- **Country profile:** https://cia.gov/the-world-factbook/countries/bhutan/

About the Author

Alex Hyde is PhD student at Newcastle University. His project focuses on understanding how large lake terminating glaciers in Bhutan are responding to climate change, with a particular interest in why some lake terminating glaciers undergo catastrophic collapse, while others retreat steadily.

He undertook a BSc in Geography at the University of Sheffield, before taking a year out to work for the UN Development Program in Kyrgyzstan; here the importance of glaciers as a water resource motivated him to return to Sheffield to complete an MSc in Polar and Alpine change, before then moving onto Newcastle University.

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