Mountains of change

The world's glaciers are shrinking, with knock-on impacts for local communities. We need a better grasp of the hazards they leave behind.

As global temperatures climb higher, mountainous environments are transforming rapidly. Mountain glaciers across much of the world are retreating^{1,2}, impacting the water supply for up to 1.9 billion people³. These dramatic changes are expected to affect mountain hazards, such as the frequency and magnitude of flooding and landslide events⁴. However, specific local impacts remain highly uncertain due to the complex interactions between the mountain cryosphere, local weather and topography⁴.

Glacial lake outburst floods are one such hazard, which occur when water breaches a moraine or glacier dam. They can be triggered by the simple build-up of water pressure, or by more abrupt events, such as an avalanche. Outburst floods can release vast quantities of water, often resulting in catastrophic consequences downstream⁴.

In the Cordillera Blanca mountains of Peru, the city of Huaraz is currently under just this sort of threat⁵. Lake Palcacocha (Fig. 1) is at risk of flooding the valley, as was the case in 1941, when an outburst flood destroyed one third of the city, tragically killing 1,800 people. A study in this issue of *Nature Geoscience* shows that global greenhouse gas emissions from human activities are almost certainly responsible.

Attributing an individual hazard to human-induced emissions is a difficult task owing to the inherent natural variability in local conditions. In the case of *flood risk from Lake Palcacocha*, Stuart-Smith et al. use a three-step process. Firstly they determine the influence of greenhouse gas emissions on local warming, secondly they establish the influence of this warming on the glacier that drains into the lake, and finally they quantify the resulting impact on local flood risk. By linking up this causal chain, the authors conclude that it is virtually certain that human-induced warming has resulted in the elevated present-day flood risk. They also argue that the 1941 disaster was an early symptom of climate warming.

These findings raise important questions surrounding liability and responsibility for local climate damages. Can policymakers and emitters of carbon dioxide be held responsible for such events? A local farmer from Huaraz believes so. In 2015, Saúl Luciano Lliuya sued a prominent German energy company for damages arising from

Credit: Alexander Luna

their alleged contribution to climate change. The lawsuit was initially dismissed, but following an appeal, it is currently in the evidentiary stage⁶. Cases such as this will look to scientifically robust attribution studies, which are likely to reach increasingly confident conclusions as datasets expand and warming impacts become more pronounced. Lawyers argue that these developments in attribution science could change the legal landscape for climate change litigation⁷.

Legal considerations aside, ascertaining human influence on distinct events is important for understanding and predicting future changes. The widespread retreat of mountain glaciers has led to a rapid increase in the number and size of glacial lakes⁸, but attempts to identify associated changes in the occurrence of outburst floods remain inconclusive⁹. Deeper understanding of how outburst flood triggers are responding to ongoing warming is needed if we are to evaluate future risks and determine where mitigation measures may be required.

The shrinking mountain cryosphere presents many other hazards for the communities who reside there. Glacier retreat can result in sudden river piracy, whereby river drainage systems rapidly reorganize, with significant downstream implications¹⁰. Degradation of permafrost can escalate rockfall hazards, making mountaineering more treacherous and impacting a critical source of income in many alpine regions¹¹.

Quantification of how such hazards are influenced by atmospheric conditions

has been hampered by the lack of comprehensive local observations in high-altitude mountains⁴. Making use of the increasing abundance of data from Earth observation satellites and incorporating local knowledge could help to plug these gaps.

The residents of Huaraz are already living under the threat of flooding from the expansion of Lake Palcacocha. Further local-scale analyses are needed to determine where else hazards may occur in future, and crucially where they may impact on local communities and livelihoods. This information is essential for informing successful mitigation and adaptation strategies to ensure a sustainable future for the world's mountain communities. □

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