Topic

Analyzing GLOF risk and factors using remote sensing in the Cordillera Blanca region of the Peruvian Andes.

Background/Introduction

As glaciers retreat and ice mass decreases through melting depressions form allowing precipitation and melt water to accumulate, forming glacial lakes. The current inventory of glacial lakes is rapidly increasing due to accelerated melting and glacial retreat caused by warming global temperatures. Glacial lakes can be categorized into three distinct types of dammed lakes: moraine dammed, ice dammed, and bedrock dammed. Bedrock-dammed lakes are bound solely by bedrock, and while dam failures can occur leading to lake drainage, it is less likely so we will ignore these lakes during the project. Moraine dammed glacial lakes occur when water accumulates between a glacier and a moraine ridge. These moraine ridges occur when glaciers advance and retreat, depositing and moving debris into mounds (Hambrey, 1994). There are two primary types of moraine-dammed lakes: end-moraine dammed lakes, where the lake exists between the moraine and the terminus (end) of the glacier and lateral-moraine dammed lakes, where the lake exists between a moraine and the lateral side of the glacier (Yao et al, 2018). Moraine-dammed lakes have an elevated risk of fracture because the moraine ridges can become extremely unstable. The final dammed-lake type is ice-dammed lakes, which occur when a surging glacier with terminus advance blocks valleys restricting flow, or when any glacial ice blocks a river and restricts drainage, causing accumulation (Emmer, 2017). Like moraine-dams, ice-dams are at elevated risk of fracturing and breaking.

When the dams of these lakes fracture and break they release a sudden rush of water that can harm downstream infrastructure and endanger lives. These "rushes of water" are named Glacial Lake Outburst Floods (GLOFs). The flood peak of a GLOF can far exceed other methods of floods, and in extreme cases the amount of water released can be in the millions of cubic meters (Costa, 1988). Within the Cordillera Blanca region of the Peruvian Andes, sixty of these GLOFS have been recorded, of which over 50% came from moraine-dammed lakes (Emmer et al, 2022). As of 2021, the high-mountain region of Cordillera Blanca, Peru, has approximately 298 dammed lakes (12 in contact with ice, 286 no contact) (Wood et al, 2021). Often the dam faces for these lakes occur at a steeper angle than the repose angle, making them increasingly unstable and at an elevated risk of having GLOFs. GLOFs from these lakes pose a risk to downstream infrastructure because they are in areas where downslope materials are highly susceptible to erosion, causing the ensuing flood waters to contain additional ice and debris (Costa, 1988). In Peru during the 20th century alone, there were over thirty thousand recorded deaths as a result from GLOFs (Carey, 2005). Given the frequency and damage that GLOFs in the Cordillera Blanca region cause, and the constant formation of new dammed glacial lakes from climate change, it is necessary for current glacial lakes to undergo comprehensive risk assessments.

Project Description

Past studies have used a multi-criteria approach to determine the likelihood a GLOF is to occur, and how destructive this GLOF would be. The goal of this research is to apply and expand

this work to recently observed lakes in the Cordillera Blanca region. Additionally, the research will leverage previously recorded GLOFs within this region, along with their risk factors to determine the accuracy of our approach. With a successful project, we will have a better understanding of what factors cause GLOFs, what determines destructivity, and how at risk current glacial lakes are.

This project will assess GLOF risk using the following criteria:

1. Triggering Factors

   o   Slope above lake

   o   Ice/rock avalanche potential

   o   Slope between lake and glacier

   o   Significant weather events (i.e. large precipitation)

   o   Seismic Hazards

2. Destruction Factors

   o   Slope below lake

   o   Downstream distance to another lake or river

3. Dam Characteristics

   o   Dam geometry and height

   o   Material Composition (ice versus moraine)

4. Lake Parameters

   o   Volume and area

   o   Growth rate

   o   Contact with glacier

Along with other criteria discovered during the data acquisition phase.

We can use LandSat images (and other remotely sensed images), to create an inventory of glacial lakes, their dam-types, and areas, within the region of interest. To track the growth rate of glacial lakes we can use a time series of LandSat images. Examining this time series could require examining over a hundred images, so by applying different bands, we could potentially highlight the lakes because they will have different reflectance than surrounding areas. A digital elevation model can be used to calculate all slope criteria, dam height and geometry, and potentially an estimate of lake volume. To determine seismic hazards, we will use a global earthquake map (GEM). For the remaining criteria, the specific data source is still under investigation, but we plan to investigate open-source data repositories such as Data.Nasa.Gov and Zenodo.

References

Adam Emmer, Joanne L. Wood, Simon J. Cook, Stephan Harrison, Ryan Wilson, Alejandro Diaz-Moreno, John M. Reynolds, Juan C. Torres, Christian Yarleque, Martin Mergili, Harrinson W. Jara, Georgie Bennett, Adriana Caballero, Neil F. Glasser, Enver Melgarejo, Christian Riveros, Sarah Shannon, Efrain Turpo, Tito Tinoco, Lucas Torres, David Garay, Hilbert Villafane, Henrry Garrido, Carlos Martinez, Nebenka Apaza, Julia Araujo, Carlos Poma. *160 glacial lake outburst floods (GLOFs) across the Tropical Andes since the Little Ice Age*. Global and Planetary Change, Volume 208, 2022, ISSN 0921-8181, https://doi.org/10.1016/j.gloplacha.2021.103722.

Costa, J.E. and Schuster, R.L., 1988. *The formation and failure of natural dams*. Geological Society of America Bulletin, 100, 1054–1068.

Emmer, A. *Glacier Retreat and Glacial Lake Outburst Floods (GLOFs)*. Oxford Research Encyclopedia of Natural Hazard Science vol. 2017 (2017).

Hambrey, M. J. 1994. *Glacial Environments*. UCL Press.

J.L. Wood, S. Harrison, R. Wilson, A. Emmer, C. Yarleque, N.F. Glasser, J.C. Torres, A. Caballero, J. Araujo, G.L. Bennett, A. Diaz-Moreno, D. Garay, H. Jara, C. Poma, J.M. Reynolds, C.A. Riveros, E. Romero, S. Shannon, T. Tinoco, E. Turpo, H. Villafane. *Contemporary glacial lakes in the Peruvian Andes*. Global and Planetary Change, Volume 204, 2021. ISSN 0921-8181, https://doi.org/10.1016/j.gloplacha.2021.103574.

K. Johnson, M. Villani, K. Bayliss, C. Brooks, S. Chandrasekhar, T. Chartier, Y. Chen, J. Garcia-Pelaez, R. Gee, R. Styron, A. Rood, M. Simionato, M. Pagani (2023). *Global Earthquake Model (GEM) Seismic Hazard Map* (version 2023.1 - June 2023), DOI: https://doi.org/10.5281/zenodo.8409647

Mark Carey. *Living and dying with glaciers: people's historical vulnerability to avalanches and outburst floods in Peru*. Global and Planetary Change, Volume 47, Issues 2–4, 2005. ISSN 0921-8181, https://doi.org/10.1016/j.gloplacha.2004.10.007.

Yao, X., Liu, S., Han, L., Sun, M. & Zhao, L. *Definition and classification system of glacial lake for inventory and hazards study*. J. Geogr. Sci. 28, 193–205 (2018).