

Landslide runout analysis using remote sensing for Lower and Upper Barun lakes

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Abstract

Landslides are common triggers of glacial lake outburst floods in high mountain regions, but the remoteness of dangerous glacial lakes makes monitoring and disaster management very difficult. Using a very high resolution digital elevation model produced from a series of stereo satellite images, we simulate debris flows and rock avalanche runout around two very dangerous lakes in high mountain Nepal. We constrain particularly likely sources of these slope failures to simulate 79,800 potential debris flows and rock avalanches of volumes ranging from 1,000 m³ to 1,000,000 m³ near Upper and Lower Barun Lakes. This allowed us to identify zones in

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Data and Methods

Simulating landslide runout around Upper and Lower Barun Lakes required a DEM; coordinates of areas likely to be sources of debris flow and rock avalanches, which we denote as initiation points; and a series of volumes for the potential debris flows and rock avalanches.

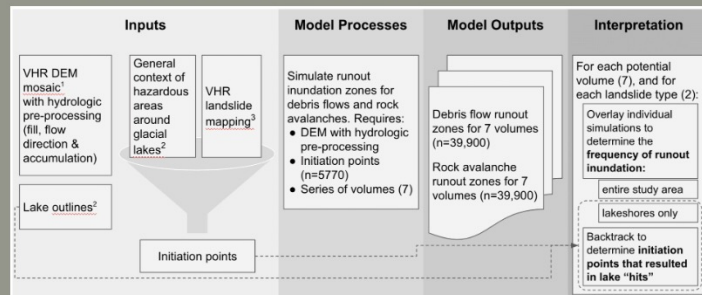
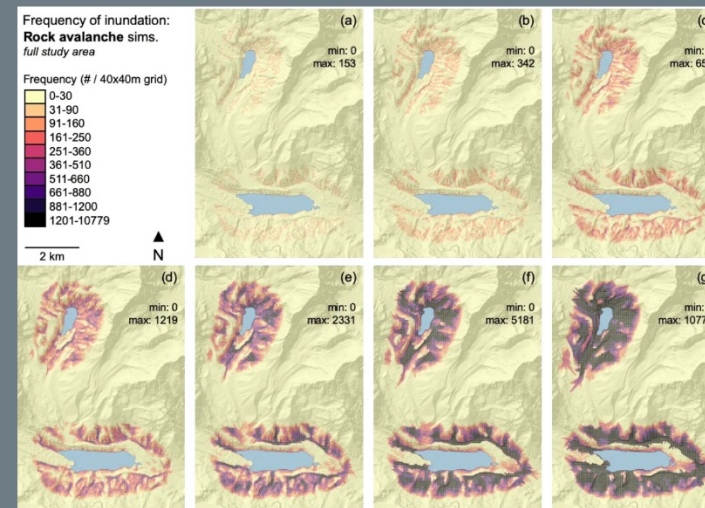


Figure 1. Overall workflow, incorporating data or methods from: (Refs 1, 2,

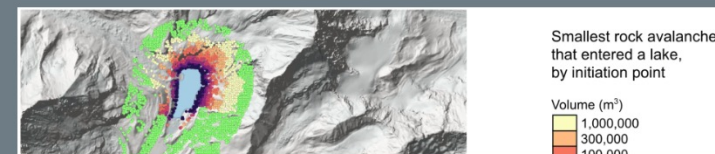
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Preliminary Results

We first examine and discuss the results of these runout simulations derived with an 8-m DEM (1) by plotting heatmaps of runout zones, and then by distinguishing which trigger areas that produced runout simulations that hit a lake. Interpretation may provide insight on lakeshore exposure and failure points or regions of concern.



Frequency of inundation by rock avalanche for volumes of (a) 1,000 m³ (b) 3,000 m³ (c) 10,000 m³ (d) 30,000 m³ (e) 100,000 m³ (f) 300,000 m³ (g) 1,000,000 m³



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Initial Findings, Uncertainties, Next Steps

Validation

- We have verified that some simulations overlap with observations of actual landslides
- Further validation is limited by a lack of knowledge of the actual volumes of mapped landslides

Uncertainties - input data, trigger zones, modeling approaches

- Since the study area was contained entirely within one WorldView scene, we do not expect errors caused by stitching scenes stereo-derived DEMs. Still, topographic artifacts (e.g., erroneous ridges or depressions) introduced from other

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Key References and Acknowledgements

1. Shean 2017. <https://doi.org/10.5067/KXOVQ9L172S2>
2. Rounce et al. 2017. <https://doi.org/10.3390/rs9070654>
3. Amatya et al. 2019. <https://doi.org/10.3390/rs11192284>
4. Iverson 1998. <https://pubs.usgs.gov/of/1998/0638/report.pdf>
5. Griswold and Iverson 2007. <https://pubs.usgs.gov/sir/2007/5276/>
6. Mergili et al. 2017. <https://doi.org/10.5194/gmd-10-553-2017>
7. Westoby et al. (2014). <https://doi.org/10.1002/esp.3617>
8. Haritashya et al. 2018. <https://doi.org/10.3390/rs10050798>
9. Kirschbaum et al. 2019. <https://doi.org/10.3389/feart.2019.00197>

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Abstract

Landslides are common triggers of glacial lake outburst floods in high mountain regions, but the remoteness of dangerous glacial lakes makes monitoring and disaster management very difficult. Using a very high resolution digital elevation model produced from a series of stereo satellite images, we simulate debris flows and rock avalanche runout around two very dangerous lakes in high mountain Nepal. We constrain particularly likely sources of these slope failures to simulate 79,800 potential debris flows and rock avalanches of volumes ranging from $1,000 \text{ m}^3$ to $1,000,000 \text{ m}^3$ near Upper and Lower Barun Lakes. This allowed us to identify zones in and around these dangerous glacial lakes that are most exposed to landslide runout hazards, along with the most frequent source areas that produced landslides that may run into either of the two glacial lakes. Although our empirical-statistical model presented limitations that numerical models attempt to overcome, our probabilistic approach combined with a very high resolution DEM may shed new light on how to identify sources and impact areas of debris flows and rock avalanches that may cascade into downstream disasters.

Data and Methods

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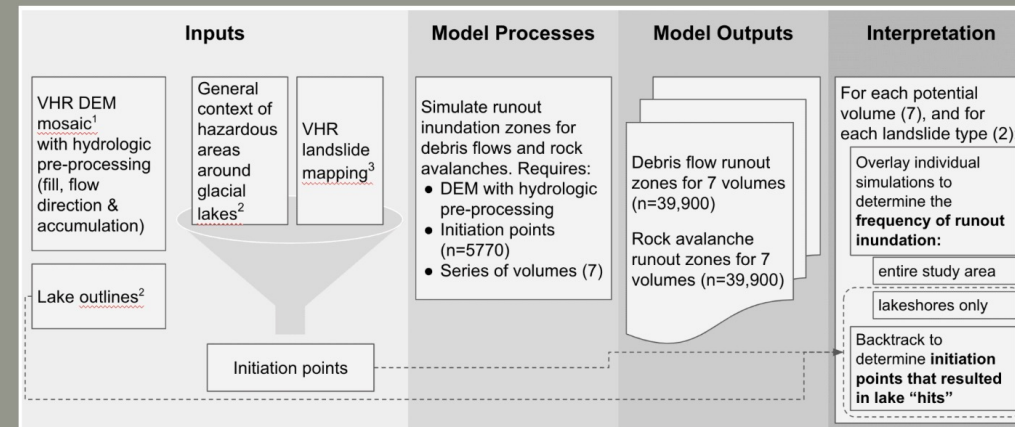


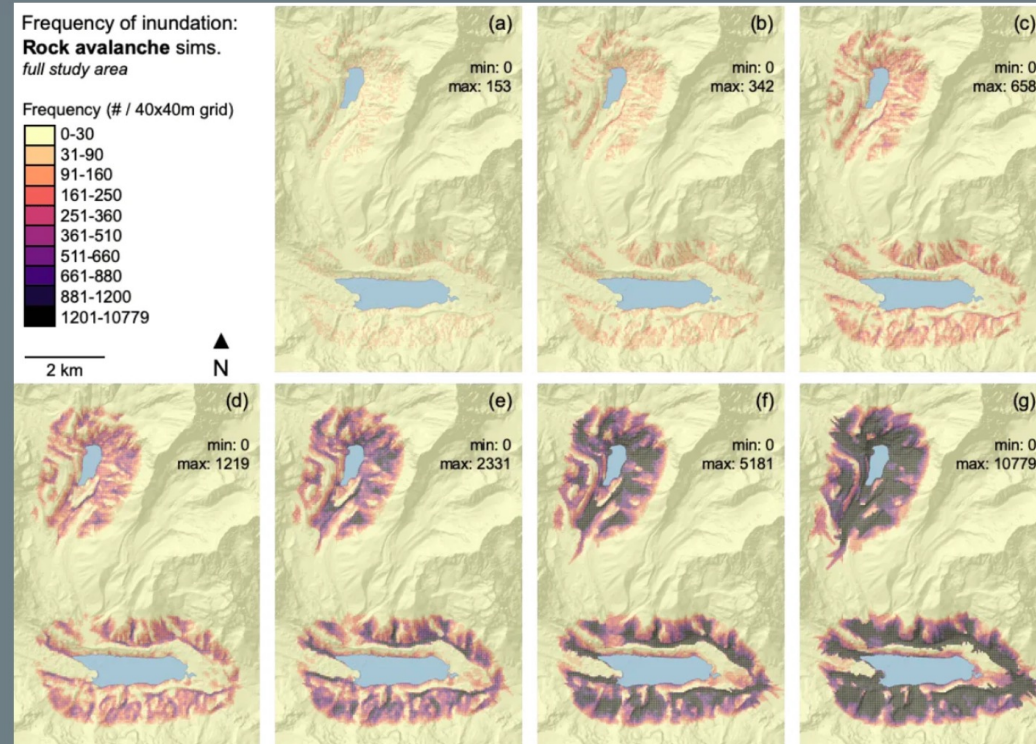
Figure 1. Overall workflow, incorporating data or methods from: (Refs 1, 2, 3) and LAHARZ (4, 5)



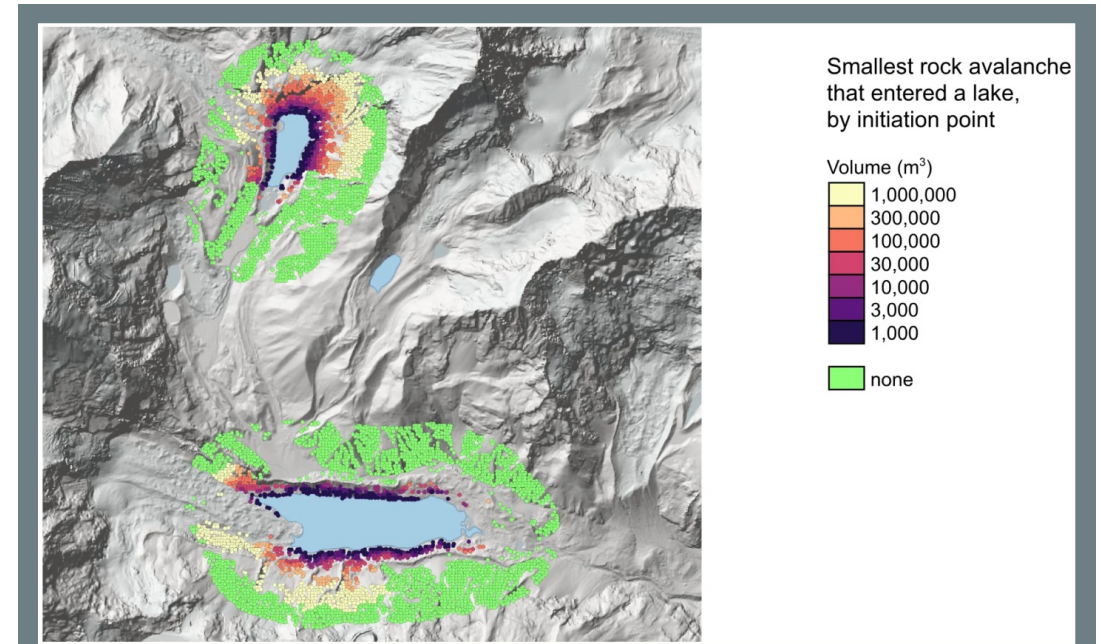
Figure 2. Study area

Preliminary Results

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Frequency of inundation by rock avalanche for volumes of (a) $1,000 \text{ m}^3$ (b) $3,000 \text{ m}^3$ (c) $10,000 \text{ m}^3$ (d) $30,000 \text{ m}^3$ (e) $100,000 \text{ m}^3$ (f) $300,000 \text{ m}^3$ (g) $1,000,000 \text{ m}^3$



The sources of the landslides simulations that hit either lakes, categorized by the smallest volume

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Uncertainties - input data, trigger zones, modeling approaches

- Since the study area was contained entirely within one WorldView scene, we do not expect errors caused by stitching scenes stereo-derived DEMs. Still, topographic artifacts (e.g., erroneous ridges or depressions) introduced from other sources in any DEM used to simulate landslide runout may negatively influence the results.
- Landslide runout simulations require knowledge of initiation points or precise failure zones. In remote, high mountain Asia, we face immense uncertainty in pinpointing exact initiation locations for rock avalanches and debris flows; however, studies have identified general areas of higher likelihood for slope failure. On one hand, we dealt with this uncertainty by running simulations for thousands of scenarios of initiation points, similar to methods used by (6) to create an impact indicator index. On the other hand, this approach could compound topographic errors introduced by DEMs by routing runout around false ridges or into false depressions, thereby concentrating such false hazard zones.
- Separate from any errors present in the DEM, the LAHARZ modeling approach does not account for the velocity and momentum of landslide debris that may run up and over channels.

- Although trigger mechanisms that could impact lake breach vary based on the location, they can be combined in four broad categories of glacier calving, unstable mass sliding into the lake, cascading events, and extreme precipitation. Based on several possible triggers in any lake failure described in (7), one of the major challenges is the unknown mass, energy, velocity and travel distance, angle at which lake could be hit by any of the triggers. In general, there is a significant momentum transfer from the slide to the water, which could be tens of meters per second. Each slide or any other matter that hits the lake will put the lake into a gravitationally unstable situation. We can provide some situational understanding in this paper, but this uncertainty remains a major factor any modeling studies.

Next steps

- Further scrutiny of the ranges of plausible volumes of landslides in this region
- More quantitative validation / verification using high resolution remote sensing
- Explore potential research and applications related to cascading hazards (8, 9). For instance, would improved knowledge on lakeshore exposure and trigger zones further our understanding of causes of glacial lake outburst floods?

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