Assessing the Impacts of Debris Coverage on Glaciers in the Andes

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Abstract

Glaciers act as hydrologic reservoirs in mountain environments around the world. In regions that are particularly water-stressed, such as the Andes, glaciers contribute significantly to water resources in downstream communities. As these glaciers recede rapidly throughout the Andes under climatic changes, the surface composition of their ablation zones appears to be shifting from predominantly clean-ice to debris-covered ice. Determining what climatological and topographical factors control debris-coverage in the ablation zones of glaciers throughout the Andes will assist in understanding why these glaciers are becoming increasingly covered by debris and how this debris coverage will continue in the future. By exploring multiple drainage basins across the Andes, this study will discover which regions are most impacted by this transition. Debris-coverage is known to have varying impacts on the ablation rates of glaciers and likely alters the sub-glacial and pro-glacial hydrology of the drainage basin they reside in. With debris-covered glaciers becoming more prevalent across the Andes, it is imperative to gain a better understanding of the hydrology of these complex cryospheric features. Through the use of terrestrial photogrammetry and hydrological techniques, this study will investigate the controls of debris coverage and assess the hydrological impacts of this debris on glaciers throughout the Andes.

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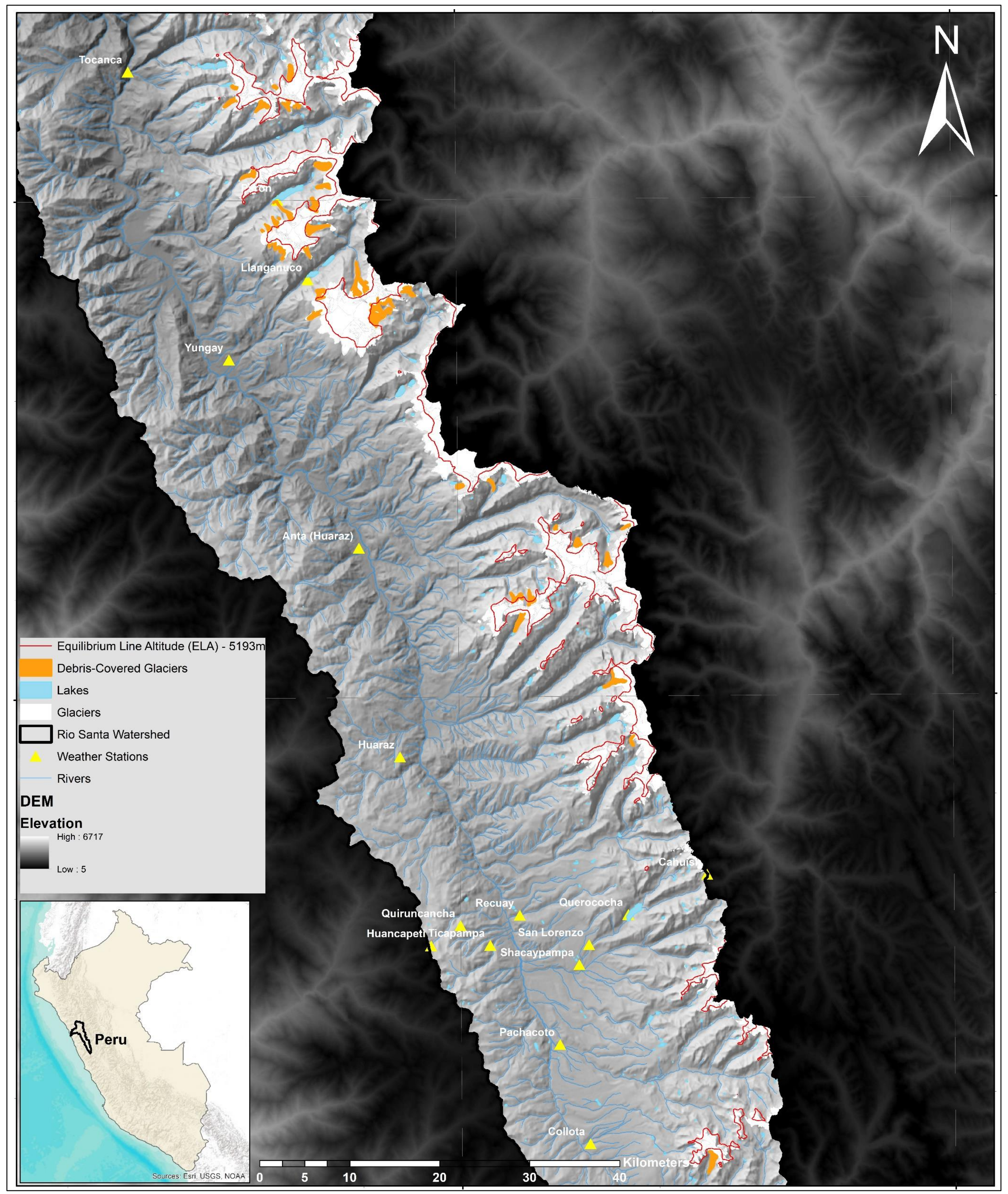
ABSTRACT

Glaciers act as hydrologic reservoirs in mountain environments around the world. In regions that are particularly water-stressed, such as the Andes, glaciers contribute significantly to water resources in downstream communities. As these glaciers recede rapidly throughout the Andes under climatic changes, the surface composition of their ablation zones appears to be shifting from predominantly clean-ice to debris-covered ice. Determining what climatological and topographical factors control debris-coverage in the ablation zones of glaciers throughout the Andes will assist in understanding why these glaciers are becoming increasingly covered by debris and how this debris coverage will continue in the future. By exploring a large drainage basin in the tropical Andes, this work will determine which localities will be most impacted by these changes. Debris-coverage is known to have varying impacts on the ablation rates of glaciers and likely alters the sub-glacial and pro-glacial hydrology of the drainage basin they reside in. With debris-covered glaciers (DCGs) as a prevalent feature across the northern Andes, it is imperative to gain a better understanding of the hydrology of these complex cryospheric features. Through the use of terrestrial photogrammetry and satellite imagery, this work will investigate the controls of debris coverage and ultimately, will assess the hydrological impacts of debris on glaciers in the tropical Andes using in situ measurements.



STUDY AREA

- Northern Tropics
  - Cordillera Blanca, Peru
    - Rio Santa Watershed
- Geology – high mountain terrain consists primarily of Cordillera Blanca batholith (8.2 Ma)
  - Valleys contain significant Quarternary glacial deposits
- Glaciers within Cordillera Blanca make up >70% of global tropical ice
- Rising temperatures are causing rapid glacial recession and shifts in local hydrology
- Major presence of agriculture, mining, cities, hydropower in basin

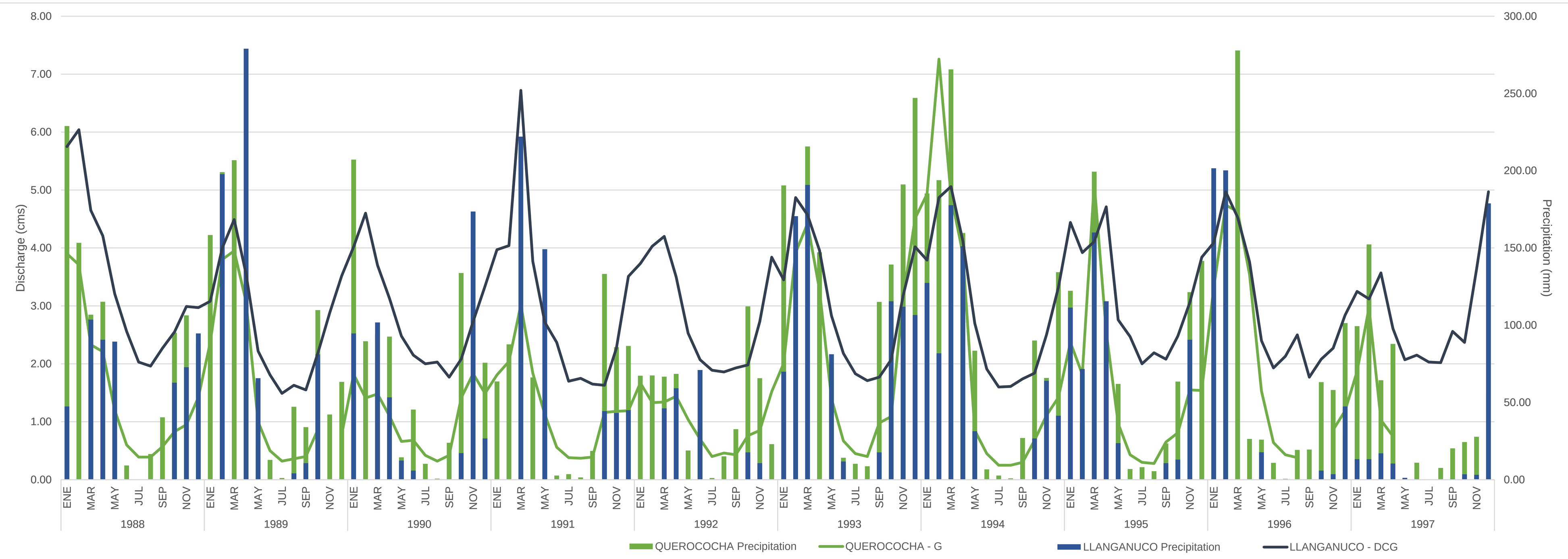
DEBRIS-COVERED GLACIERS

- Defined by continuous supraglacial rock debris across a glacier surface – typically found in the ablation zone
- Examined in Himalaya and Alps – largely through modeling techniques
  - Himalaya – regionally important buffer against drought
- Supraglacial debris impacts terminus dynamics – altering glacier response to climatic changes
- Limited knowledge of tropical DCGs and their hydrological impacts

Right: Pisco Debris-Covered Glacier, Llanganuco Valley, Cordillera Blanca – Note the ice cliff in the foreground of the image and the continuous debris-coverage between the moraines

Above: Kinzl Debris-Covered Glacier, Llanganuco Valley, Cordillera Blanca – Note the transition from clean-ice to debris-covered at higher elevations (left side), and the continuous debris covering ice between the lateral moraines

Below: Historical hydrograph from a catchment with extensive debris-coverage (blue) and a catchment with only clean-ice (green)



WORKFLOW

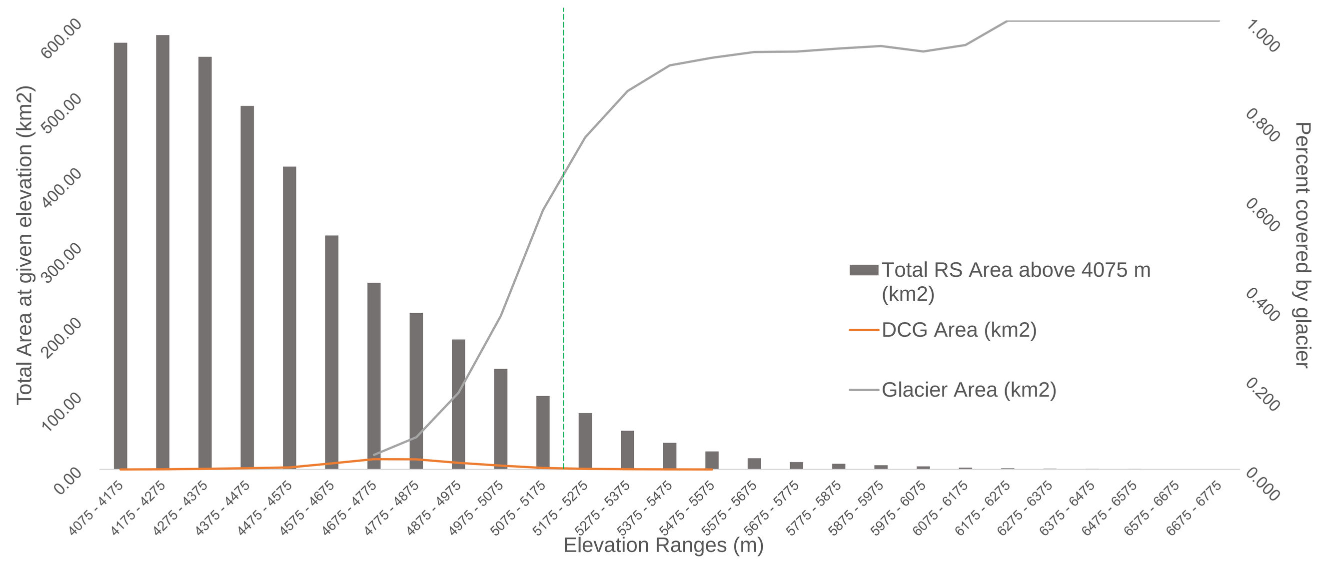
- Factors considered in inventory:
  - Area (km²); Minimum/Mean/Maximum Elevation (m.a.s.l.); Slope (°); Aspect(°); Latitude/Longitude
- Assess current location and distribution of DCGs
  - Will assist in determining drainage basins containing comparable DCGs and glaciers
- Calculated Equilibrium Line Altitude (ELA) using a generalized empirical equation from Condom et al. (2007) specifically created for calculating ELA between 5°S and 20°S:

$$ELA = 3427 - 1148(log10(P) + \frac{T}{0.007} + z$$

where P is mean annual precipitation (mm/yr), T is mean annual temperature (°C), and z is the elevation of the weather station (m a.s.l.)

- Ultimately compare discharge from glaciated catchments with and without extensive debris-coverage across the Cordillera Blanca

Rio Santa Glacier Statistics	Debris-Covered	Clean-Ice	All Glaciers
Average Glacier Area (km2)	0.49	1.06	0.99
Total Area (km2)	35.01	413.03	448.04
Average Minimum Elevation (m)	4635	4917	4883
Average Elevation (m)	5139	5218	5209
Average Slope (deg.)	12.7	28.6	27.5
Mean Aspect (deg.)	202.7	210.2	209.3
Longitude	-77.57	-77.49	-77.51
Latitude	-9.12	-9.25	-9.23
Number of glaciers analyzed (n)	45	331	376



FUTURE DIRECTIONS

- Expand in situ data collection to include the DCGs in the tropical Andes
- Understand the hydrological significance of DCG in the Tropics
  - Downstream discharge and water quality changes
  - Influence on local communities and other users of the water resources
  - Determine the influence of glacier debris surface composition and distribution on pro-glacial hydrology
- Determine climatological and topographical controls on debris-coverage
  - Creating an expansive dataset containing possible factors that drive debris cover in the Cordillera Blanca
- Develop mixed methods to assess changes in volume, not only areal changes
- Compare results to DCG studies in non-tropical regions (i.e. Himalaya, Alaska)

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