Evaluation of inter-annual to decadal changes in tropical Andean stream chemistry below debris-covered glaciers

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Abstract

The rapid retreat of tropical glaciers in the Cordillera Blanca, Peru, results in significant changes to the quality and quantity of the streamflow below. Debris-covered glaciers are a common feature in this region but have previously only been studied in terms of their geomorphology and surface characteristics. Short term studies have used hydrochemical mixing models to estimate contributions of melting glaciers to down valley streams. The progressive impact that these glaciers have on streamflow and water chemistry as climate change continues to force glacier loss has yet to be examined. Here we analyze a 16-year dataset (2004-19) of water samples collected from glacierized tributaries of the Santa River draining the Cordillera Blanca, Peru to evaluate inter-annual to decadal differences in hydrochemistry in the outflows below debris-covered glaciers and debris-free glaciers. This unique dataset consists of annual dry season samples from 48 sites within 20 tributaries with different amounts of glacier coverage that provide the isotopic and ionic composition of the water, allowing for analyses of patterns within catchments and comparisons between them over time. Within the Llanganuco catchment, the Kinzl glacier tongue descending from Peru's highest summit of Huascaran is heavily debris covered (4350-5200 m). Samples directly from the Kinzl effluent stream show the most negative (δ18O = -16.79(δ18O difference = 3.84watershed. In contrast, the Broggi drainage displays the least negative (δ18O = -14.10Finally, to gain a regional perspective we use the synoptic samples throughout the Callejon de Huaylas watershed to provide a comparison to previous estimates of specific discharge from glacier melt.

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INTRODUCTION

Changing cryospheric conditions in the tropical Cordillera Blanca, Peru have lasting impacts on downstream water resources. By assessing isotopic signatures of $\delta^{18}O$ and $\delta^{2}H$ in glacial streams, how do debris-covered glacier (DCG) outflows chemically differ from those of debris-free glaciers?

METHODS

Fieldwork

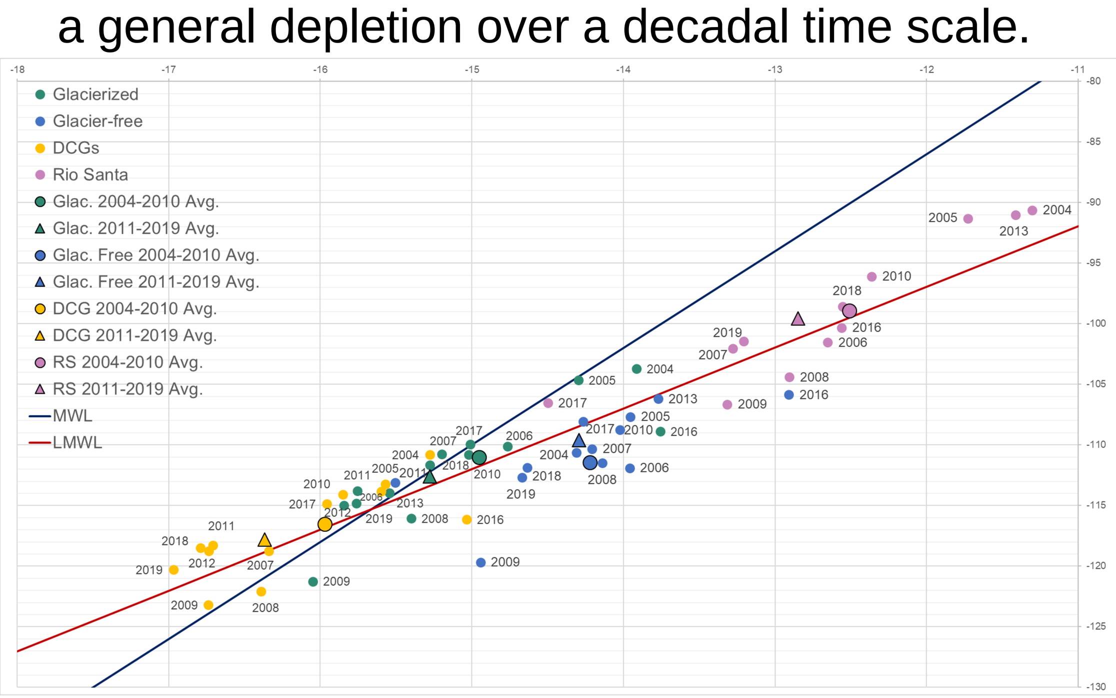
- 48 sampling locations across 20 catchments
  - 3 catchments contain DCG
- 15 years of synoptic sampling during dry season
- Began to focus on DCG outflow over past 2 years

Processing

- Picarro Isotope Analyzer and Ion Chromatography

RESULTS

- DCG $\delta^{18}O$ signal consistently lighter than debris-free glaciers
- DCG outflows also contain fewer ions
- All glacial sources in the Cordillera Blanca show a general depletion over a decadal time scale.



DISCUSSION

- Post-depositional enrichment of $\delta^{18}O$
- Less evaporation below debris than clean ice
- Findings show similar trends to the central Andes, but differ from the Himalaya (see table)

Further Analysis

- PCA, mixing models to determine contributions

Study_Reference	Outflow_Site_Name	Location	Elevation	D18O
Wilson et al., 2016	Khimsung Glacier Post-monsoon median	Himalaya	4166	-15.94
	Lirung DCG Post-monsoon median	Himalaya	3784	-15.47
Crespo et al., 2017	Mean DCG outflow value	Mendoza Andes	N/A	-20.20
	Mean Glacier outflow value	Mendoza Andes	N/A	-19.37
	Mean from downstream rivers	Mendoza Andes	N/A	-18.01
This study	Kinzl DCG median	Cordillera Blanca	4250	-16.34
	Yanamarey Glacier median	Cordillera Blanca	4031	-15.24
	Broggi Glacier median	Cordillera Blanca	3905	-15.90

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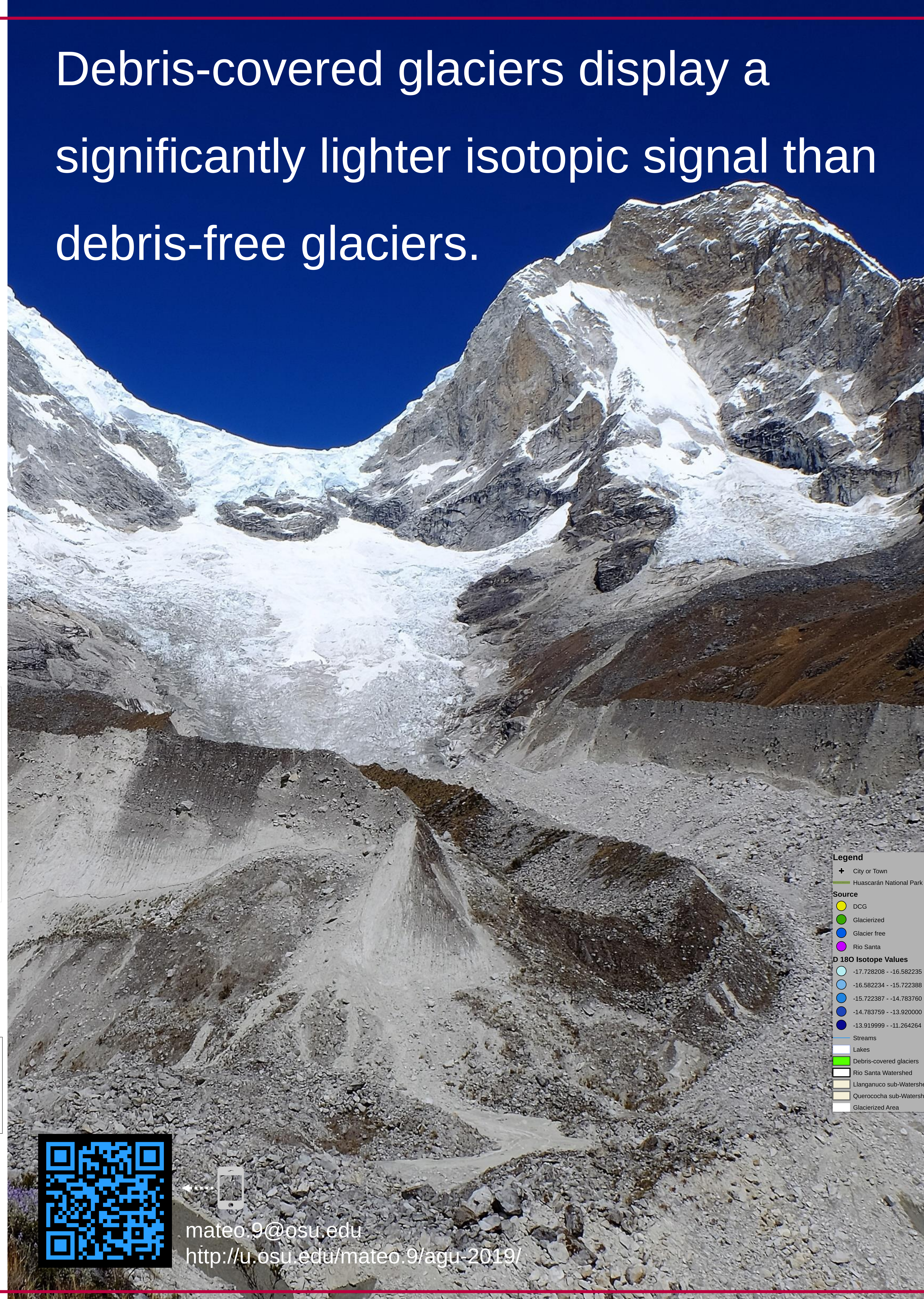

Debris-covered glaciers display a significantly lighter isotopic signal than debris-free glaciers.

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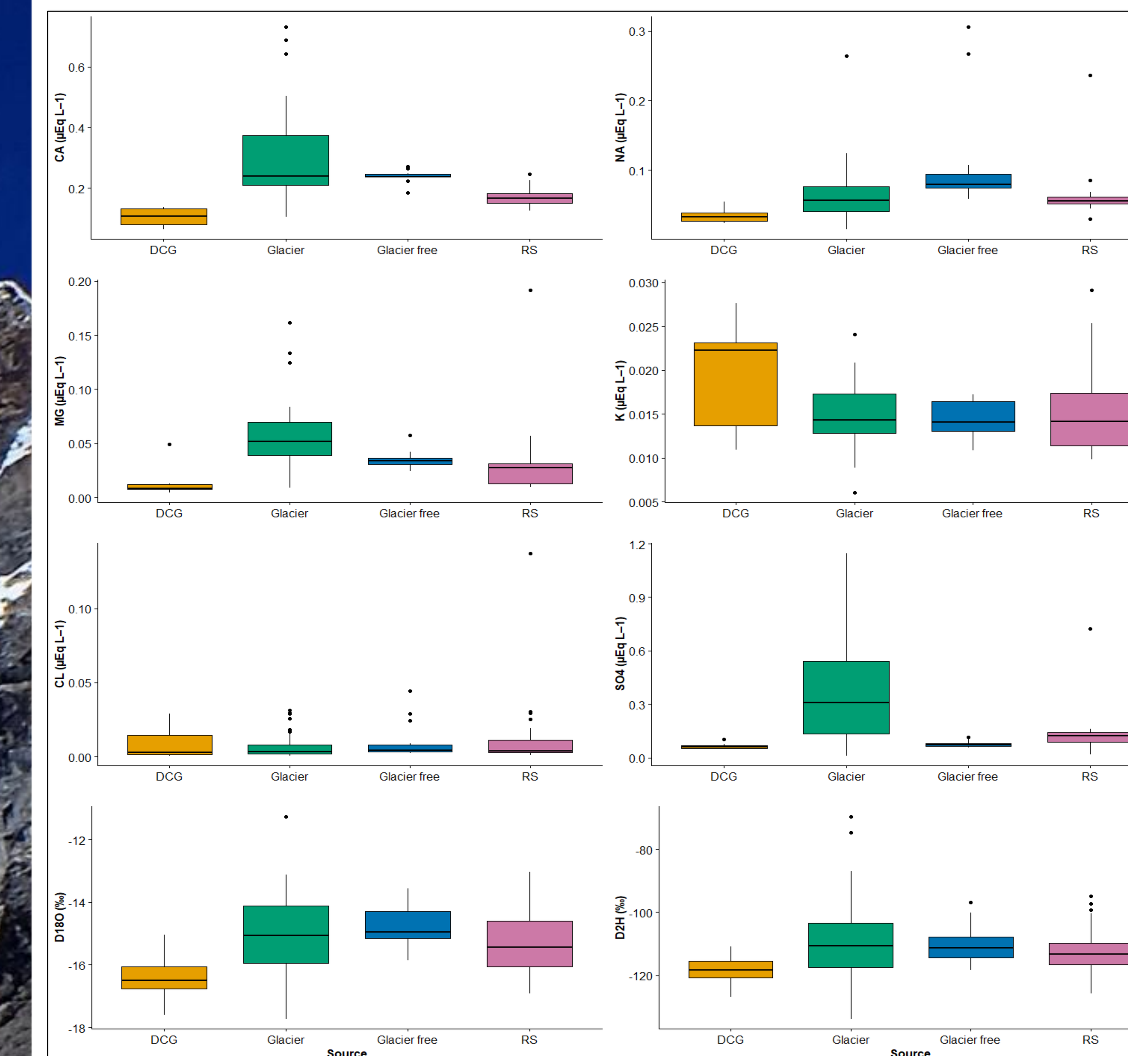
Source	count	mean	sd	max	min	range
DCG	25	-16.37489	0.6505663	-15.03528	-17.60182	2.566543
Glacier	83	-15.05923	1.2812916	-11.26426	-17.72821	6.463944
Glacier free	22	-14.80705	0.6521011	-13.55632	-15.84643	2.290113
RS	47	-15.24202	1.0482454	-13.03909	-16.91000	3.870906

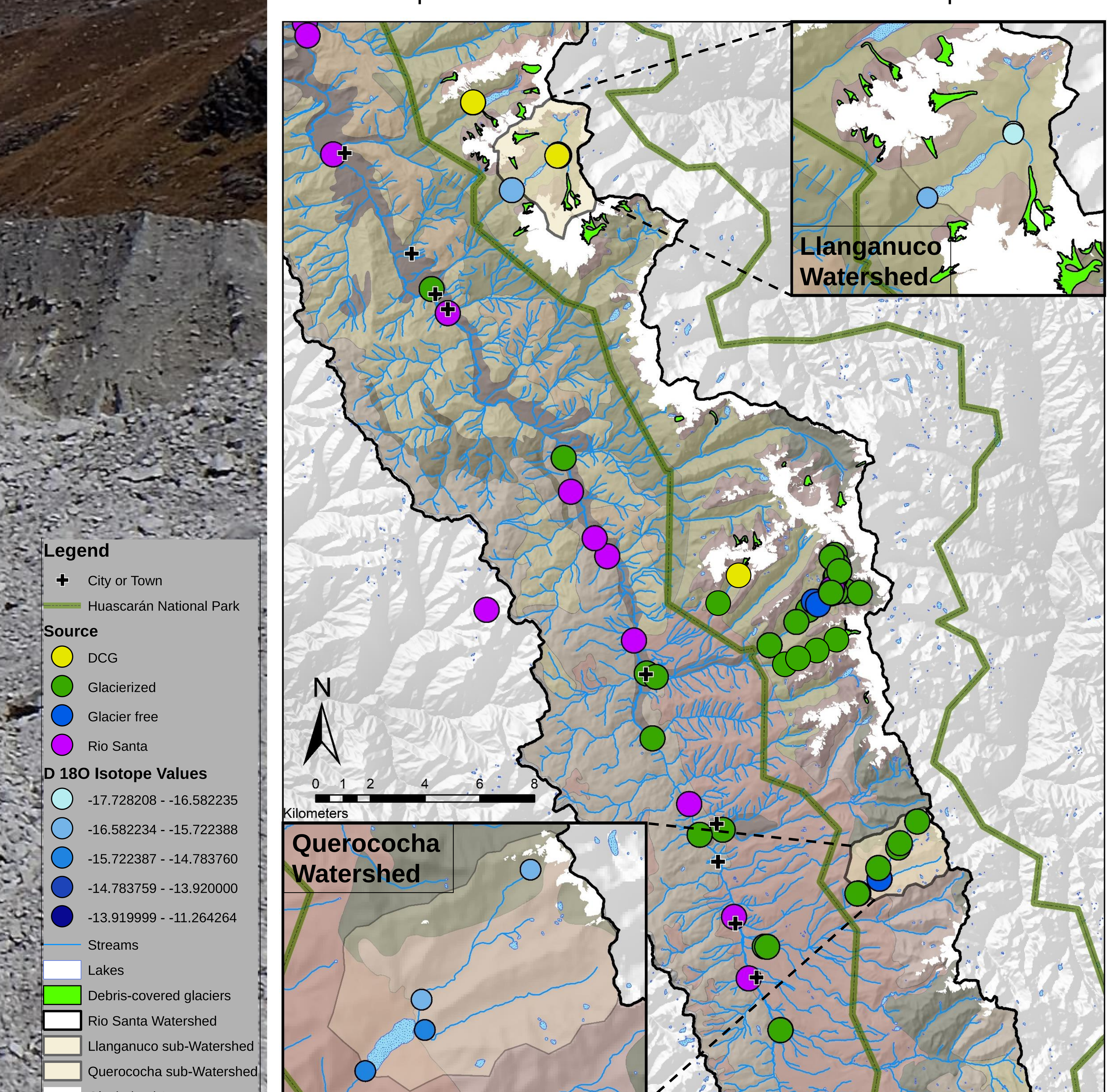
Comparison	D18O	D2H	d.excess	Ca	Na	Mg	K	Cl	SO4
Glacier - DCG	**0.0001**	**0.0088**	0.1669	**0.0003**	0.3609	**0.0046**	**0.0442**	0.9921	**0.0011**
Glac.Free - DCG	**0.0003**	0.0566	**0.0325**	0.0558	**0.0040**	0.4666	0.0669	0.9988	0.9993
RS - DCG	**0.0020**	0.1124	0.0889	0.5307	0.4682	0.4949	0.1409	0.9404	0.8378
Glac.Free - Glacier	0.8378	0.9996	0.4964	0.3872	**0.0151**	0.1302	0.9895	0.9310	**0.0001**
RS - Glacier	0.9030	0.7959	0.9285	**0.0001**	0.9986	**0.0133**	0.9342	0.4563	**0.0001**
RS - Glac.Free	0.5929	0.8800	0.8139	0.2803	**0.0225**	0.9953	0.8908	0.9528	0.8280

Above: Descriptive statistics and p-values from the Tukey HSD test for multiple mean comparisons



Above: Boxplots comparing geochemical (μEq/L) and isotopic tracers (‰) in tributaries to the Rio Santa separated by end-member source (Debris-covered glacier (DCG), Rio Santa (RS))

Below: Map of the Rio Santa Watershed with water sample locations



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