Biological monitoring of water quality and potential sources for remediation of naturally acidified headwaters in the Cordillera Blanca, Peru

Raúl Loayza-Muro
Laboratory of Ecotoxicology – Faculty of Sciences and Philosophy
Universidad Peruana Cayetano Heredia
E-mail: raul.loayza@upch.pe

Introduction

The Peruvian Andes contain more than 12,000 high altitude lagoons and the world's largest fraction of all tropical glaciers in the Cordillera Blanca. These freshwater reservoirs play a valuable role providing ecosystem services to large human populations living downstream[1]. Environmental conditions are changing in this region because of the general increase of temperature due to climate change. This is leading to altered hydrological cycles, being ~40% of the present discharge in the Santa River during the dry season originated from non-renewed glacier melt[2]. Simultaneously, the retreat of glaciers results in the weathering and leaching of metal-rich rocks, producing natural acid drainage and mobilization of high metal concentrations into water bodies. These acid and metal inputs usually exceed the Peruvian and international standards for protection of aquatic biodiversity, agriculture and human use, thus impairing the quality of headwater sources and streams at high altitudes[3].

Despite the potential impacts of climate change on Andean headwaters, little research has been devoted to study how highland-lowland interactions, including water quality and biodiversity, might be affected by natural acid and metal drainage. Therefore, the aim of this study was to determine physical chemical conditions of lagoons and rivers along the Quilcay basin and to explore how native biodiversity can be used to monitor and improve water quality. To this purpose, the following objectives were set: to build a base-line of water quality; to describe aquatic invertebrate community composition as an indicator of stream health; and to explore the potential use of vegetation for remediating water pollution. These activities involve academic institutions, organizations for the conservation of mountain ecosystems, rural communities in glacial watershed areas, and stakeholders involved in water management and climate change adaptation programs.

Materials and methods

The study is developed in the Quilcay basin, in the Cordillera Blanca area, Peru. Five sites were chosen: the Churup Lagoon and river (considered as reference sites), the Shallap Lagoon and river (polluted), and the Quilcay river (polluted) downstream the confluence of these two gorges (Figure 1). At each site, pH, temperature and conductivity were measured using a field meter. For total metals analysis water samples were analyzed by induced-coupled plasma emission spectroscopy (ICP-ES). All measurements and samplings were performed in triplicate. To determine the composition of the invertebrate community three Surber net samples (500 µm) will be collected from representative microhabitats, such as stones and still water along the banks. Samples were sieved in the

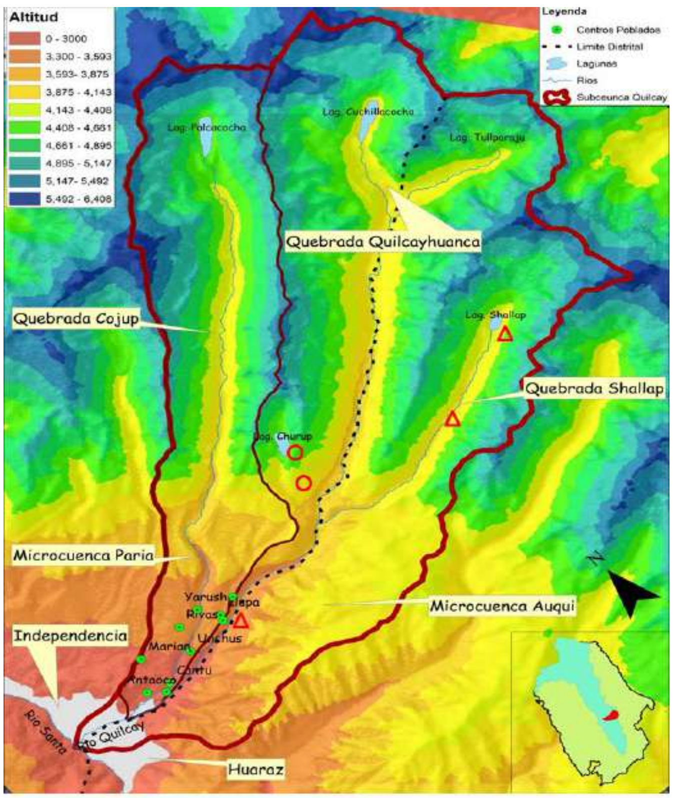

__Figure 1.__ Map of the study sites in the Quilcay basin (Cordillera Blanca area, Peru). Symbols are as follows: open circles (Churup Lagoon and river) represent clean sites; open triangles (Shallap Lagoon and river, and Quilcay river) represent polluted sites.

field, identified in the laboratory using regional taxonomical keys and used to calculate the abundance, species richness and the BMWP (Biological Monitoring Working Party) and ASPT (Average Score per Taxon) indices. These are used for classifying water quality and are based on invertebrate families showing different sensitivities to pollution. The sum of the values of each family gives a final score matching specific quality ranges represented by colors (red: high pollution; orange: low pollution; yellow. fair; green: good, and blue: excellent)[4]. Hence, water quality can be indicated in color in a map of the Quilcay basin allowing an integrated view of the interaction between highland and lowland processes. To determine the potential use of vegetation for remediating metal polluted waters, the three most abundant plant species were collected and treated for analysis by ICP-ES. All these samplings were performed in March 2013, and will be completed in July and November.

Results and discussion

Chemical analysis and environmental quality

The results indicate that reference sites have better water quality than polluted sites, being the latter characterized by acid conditions and high metal concentrations (Table 1). Among these metals, aluminum, iron, manganese and zinc, exceed the national environmental quality standards for several categories, such as surficial water for production of potable water, agricultural and cattle rising use, and conservation of the aquatic environment. This suggests that acid drainage from metal-rich bedrock occurring in the headwaters of the Quilcayhuanca and Shallap gorges due to glacier retreat may impoverish water quality at the sources and also downstream. This may imperil human health and activities such as agriculture and cattle rising in rural communities, which are constantly exposed to polluted rivers and streams. Moreover, sediments in acid streams tributaries to the Shallap river showed elevated metal concentrations (Table 2), which can be removed and mobilized downstream by the water current. As for the polluted waters described above, metals adsorbed to sediment particles can be readily accumulated in soils and vegetables, and ingested by people and cattle thus being potentially harmful, especially toxic metals such as aluminum, arsenic, cadmium, chromium and manganese[5].

Table 1. Mean values of water physical chemical parameters and metal concentrations (mg/L) at five sites in the Quilcay basin in the Cordillera Blanca area, Peru. Ref = reference; Poll = polluted.

Status	Site	Altitude (m)	pH	Conductivity (uS/cm)	Temperature (°C)	Al	Ca	Co	Fe	Mn	Si	Sr	Zn
Ref	Churup Lagoon	4467	7.5	46	10.8	ND	4.07	ND	ND	ND	1.51	0.02	ND
Ref	Churup river	3852	7.44	37	9.1	ND	4.07	ND	ND	ND	1.51	0.02	ND
Poll	Shallap Lagoon	4280	3.66	176	9.2	2.72	5.82	0.02	3.17	0.44	2.61	0.02	0.22
Poll	Shallap river	4161	4.13	112	8.7	1.52	5.06	ND	0.92	0.29	2.05	0.02	0.15
Poll	Quilcay river	3301	4.59	119	9.7	1.45	8.02	ND	1.62	0.34	2.97	0.04	0.12

ND. Non detectable

Table 2. Mean values of metal concentrations (mg/L) in sediments from an acid stream in the Shallap gorge.

	Al	As	Ba	Cd	Co	Cr	Fe	Mn	Mo	Ni	Sr	Ti	V	Zn
Shallap	9430	541.5	63.2	2.875	11.1	9.8	121000	735.5	69.45	5.15	43.8	518.5	45.3	90.65

In order to explore sustainable strategies to mitigate the impacts of acid and metal drainage arising from glacier retreat in the headwaters, we analyzed the concentration of metals in plants collected in an acid stream in the Shallap gorge (Table 3). The results indicate a high metal accumulation in plant tissues, which suggests that these species could be promising candidates for removing metals from polluted waters and sediments in artificial wetlands, as demonstrated in similar areas of the Santa river catchment[6].

Biodiversity

Different macroinvertebrate taxa were identified at all sites, being the reference Churup lagoon and river dominated mainly by sensitive crustaceans (Gammaridae), dipterans (Simuliidae), mayflies (Baetidae) and caddisflies (Odonotoceridae and Leptoceridae). On the contrary, polluted sites were mostly inhabited by taxa known for their tolerance against harsh environments, such as dipterans (Chironomidae) and colepterans (Elmidae and Scirtidae) (Table 4). This indicates that harsh acid and metal conditions may drive benthic invertebrate community composition towards more tolerant species, replacing the sensitive ones, which may negatively affect the sustainability and integrity of aquatic food webs[3,7]. These functional responses also suggest that aquatic invertebrate communities can be used as a sensitive, reliable indicator of water quality. Indeed, the reference sites had a higher BMWP and ASPT scores, which are used worldwide as biotic indices of aquatic ecosystem health[8]. Although these are preliminary results which need to be averaged with values from the next dry and rainy seasons, they suggest that native biodiversity is a valuable tool for evaluating environmental and water quality in Andean high altitude streams.

Table 3. Mean values of metal concentrations (mg/L) in plants from an acid stream in the Shallap gorge.

	Al	As	B	Ba	Cd	Co	Cu	Fe	Mn	Mo	Pb	Sr	Ti	U	V	Zn
Plant A	362	215	26.5	29.1	2.8	4.6	5.94	35500	447	34.0	ND	167	6.5	36	63.6	160
Plant B	190	132	22.6	24.5	4.2	3.2	3.33	36550	241	21.9	ND	143	7.3	24	19.7	139
Plant C	2850	790	7.8	60.9	ND	6.0	7.83	184000	195	35.4	13	82	194	33	17.0	103

ND. Non detectable

Table 4. Total number of individuals per macroinvertebrate taxon collected at five sites in the Quilcay basin in the Cordillera Blanca area, Peru.

	Churup Lagoon	Churup river	Shallap Lagoon	Shallap river	Quilcay river
Order/Family					
Non-insects					
Arachnida			1		
Gammaridae	121	1	1	1	
Copepoda	3				
Tubificidae		1			
Insects					
Diptera					
Simuliidae	1	23		1	1
Chironomidae	7	15	49	1	25
Tipulidae	1	3			
Tabanidae		2			1
Muscidae		1	1		
Empididae			1		1
Ceratopogonidae				1	2
Coleoptera					
Elmidae		3			1
Scirtidae			1		1
Ephemeroptera					
Baetidae	18	11			
Plecoptera					
Perlidae		1			
Trichoptera					
Odontoceridae	3	1			
Leptoceridae	1	3			
Hydrobiosidae		1		1	
BMWP	48	101	22	21	26
ASPT	6	7.8	3.7	4.2	3.7

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