Arsenic in the Environment: Bridging Science to Practice for Sustainable Development –
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Factors controlling varying arsenic concentration in the Copiapó River, Atacama Region, Chile

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ABSTRACT: For the most part of the Copiapó River (between 20–100 km from the headwaters, corresponding to Lautaro Reservoir and Piedra Colgada sector respectively), Arsenic content is below the Chilean norm for potable water of 0.01 mg/L. However, in its catchment area located in the Andean Cordillera, some of the tributaries have relatively higher arsenic concentration, of both geogenic and anthropogenic origin, affirmed by the presence of arsenic bearing mineralization and mining activities in the area. A spike in the Arsenic concentration can be observed close to the city of Copiapó (Km. 100 from the headwaters) can be attributed to a local contamination source that not only contributes arsenic, but a wide spectrum of different metals. Downstream, Piedra Colgada onwards, arsenic concentration increases again. This increase however is due to contribution from very old (not dated, but chemically highly evolved) aquifer in that sector that has elevated arsenic concentration.

1 INTRODUCTION

Copiapó, capital of the Atacama Region in northern Chile, is located on the banks of the Copiapó River (Figure 1). Between 1997 and 2015, the river had dried due to the lack of precipitation and partly due to overexploitation. Heavy rains in the catchment area of the river on March 25 in 2015 (Barrett *et al.*, 2016; Bozkurt *et al.*, 2016; Jordan *et al.*, 2019; Rondanelli *et al.*, 2019; Wilcox *et al.*, 2016) not only caused the reappearance of the river, but also led to heavy flood that affected the entire region with contaminated water and mud from mineral-rich higher sectors, besides causing several casualties and substantial economic damage. Likely, potential arsenic (As) content of the dust caused by dried mud was one of the major concerns for the local population inhabiting several mining towns, including Copiapó. This study involved measurement of As, and other toxic element concentrations in the Copiapó River carried out in two different seasons.

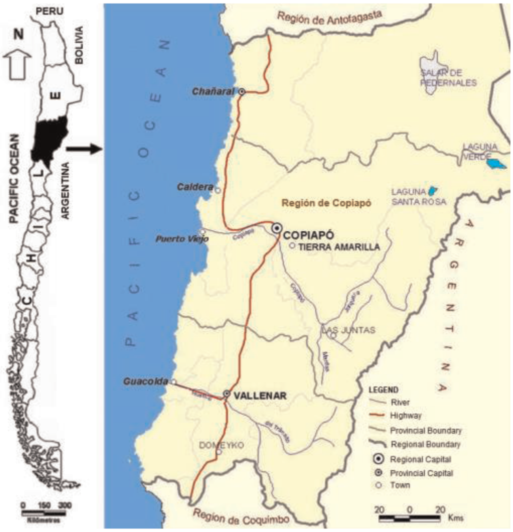

Figure 1. Study area, showing the Copiapó River, its tributaries, and major towns in the administrative region of Atacama, Chile.

2 MATERIALS AND METHODS

2.1 *Study area*

The Copiapó River (Figure 1) is located in the Atacama Desert's southern part – one of the driest places on the Earth. Its basin has a surface area of 18,400 km^2 (DGA 2004) and receives rare precipitation. It originates at the Jonquera and the Pulido rivers' confluence at La Junta, and is joined by the Manflas River at about 2.5 km downstream. It runs for about 160 km westwards before flowing into the Pacific Ocean close to the old port

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town of Puerto Viejo. It initially flows northwestward through Quebrada Paipote (Paipote Ravine) for about 90 km; however, it flows roughly westward after passing through the regional capital Copiapó.

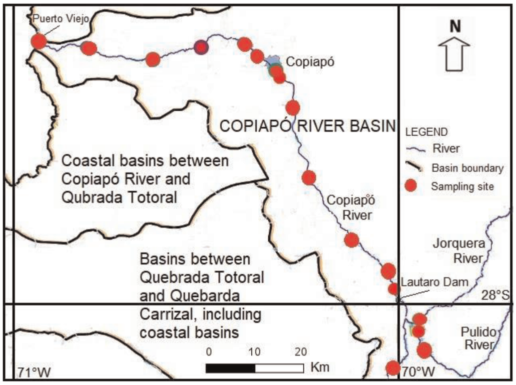

Figure 2. Sampling sites along the course of the Copiapó River. Also shown are the official hydrographic basin boundaries first established in 1978 (DGA 1978; 2013; 2014; SUBDERE 2013).

2.2 *Mud and dust sampling and analysis*

Samples of the mud spread throughout the city of Copiapó following the flood of the Copiapó River, and airborne dust of the dried mud was analyzed using X-ray fluorescence and atomic absorption techniques Universidad de Atacama. X-ray fluorescence analyses (XRF) were conducted in El Salvador in a private company, while Atomic Absorption Spectroscopy (AAS) analyses were carried out at the Pontificia Universidad Católica de Chile, Santiago.

2.3 *Water sampling and analysis*

Water samples were collected, and in situ measurements of physicochemical parameters were done during two sampling campaigns in October 2017 and June 2018. Water samples were taken from the origin of the river east of Laturao Dam at La Junta to Puerto Viejo. It falls into the Pacific every 10 or 20 km, depending upon the accessibility. It is important to mention that the first two data points belong to the Copiapó River's tributaries, and different tributaries (Manflas, Jorquera) were sampled in the two sampling campaigns.

Samples were analyzed using ICP-MS at Activation Geological Services, Coquimbo, for elemental chemistry, throughout the river course (Table 1).

Table 1. Variations in the concentration of arsenic along the course of the Copiapó River during the two sampling periods.

Sampled on 10/25/2017		Sampled on 06/01/2018	
Km*	As	Km*	As
0	2.3	0	13
10	15	12	4.1
20	11	20	9.1
30	7.9	38	6.5
60	7.1	60	6.1
80	6.7	80	6.3
95	7.3	95	7.4
100	7.6	100	8.8
115	8.9	115	7.1
130	12	130	8.6
150	12	150	9.6
160	5.5	160	11
170	3.6	170	8.3

Notes
*Distance from headwaters. As: Arsenic concentration in μg/L.

3 RESULTS AND DISCUSSION

3.1 *Arsenic concentration in mud and dust*

Arsenic concentration measured in the mud and dust samples using X-ray fluorescence was well below 100 mg/L. The results were corroborated further by atomic absorption analysis of the samples, which gave As concentration values of around 5 mg/L in all the cases. The difference in the values obtained using these two methods could be attributed to the low solubility of As-bearing minerals in the water. Although Chile does not have a norm establishing a permissible limit for toxic elements, including As, in sediments and soil, the obtained values for mud and soil are within the established legal limits in many countries (Teaf *et al.*, 2010 and references therein).

3.2 *Arsenic contamination in Copiapó River*

As concentration variation through the course of the river (Figure 3) shows that it is below the permissible limit for As in potable water of 10 μg/L in Chile (NCh 409 2006) in most of its course, specifically between 20 and 100 km, corresponding to Lautaro Dam and Piedra Colgada sectors respectively. However, in the headwaters section, its two tributaries show As concentration of up to 13 and 15 μg/L of both geogenic and anthropogenic origin, affirmed by the presence of arsenic bearing mineralization and mining activities in the area.

A spike observed close to the city of Copiapó (Km. 100) can be attributed to a local contamination source that not only contributes As, but a wide

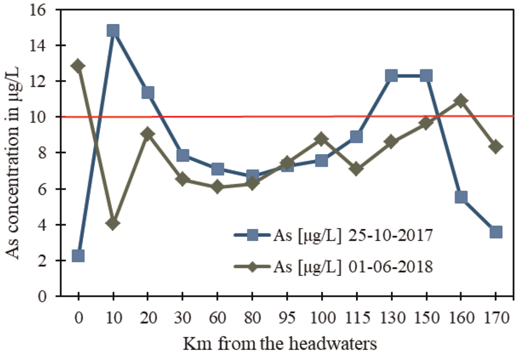

Figure 3. As concentration variation along the Copiapó River.

spectrum of different metals. Downstream, Piedra Colgada onwards, As concentration exceeds the permissible limit of 10 µg/L. This is due to the contribution from very old (not dated, but chemically highly evolved) aquifers in that sector that feed the river.

4 CONCLUSIONS AND RECOMMENDATIONS

Water quality monitored throughout the Copiapó River course shows that in most of the river sections, As concentration was below the Chilean guideline for drinking water of 10 µg/L (NCh 2005). However, in the upper section of the catchment within the Andean Cordillera, its tributaries have relatively higher As concentrations (>10 µg/L), of geogenic origin, affirmed by the presence of As-bearing mineralization in those areas. On the other hand, the aquifers feeding the river contribute As to it in the downstream area. It can be concluded that As contamination of the Copiapó River is mostly of geogenic origin.

Although As concentration in the mud and dust of the Copiapó city is not at a hazardous level, it needs to be monitored following flooding events in the future. Water quality of the Copiapó River should be monitored continuously at closer intervals throughout the river for toxic elements, including As to ascertain the point sources in order.

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