Case Studies in Peru, Bolivia and Chile on Catchment Management and Mining Impacts in Arid and Semi-Arid South America - Results from the CAMINAR Project

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Abstract
In the Chili River Basin (Peru), currently impacts of mining on water quality and quantity are minor due to good practices, but the river is polluted by untreated sewage from Arequipa city. The Lake Poopo and Uru Uru basin (Bolivia) is heavily contaminated by abandoned and active mining operations ranging from informal and cooperative miners to international mining companies. Additionally, the toxic metal-bearing host rocks cause pollution of geogenic origin. In the Elqui River Basin (Chile), the major concerns relate to conflicts about water quantities used by mining and agriculture, respectively, as well as contamination risks due to flash floods of abandoned tailing deposits in El Niño years.

Key words: integrated river basin management, water and sediment contamination, heavy metals, arsenic, stakeholder participation

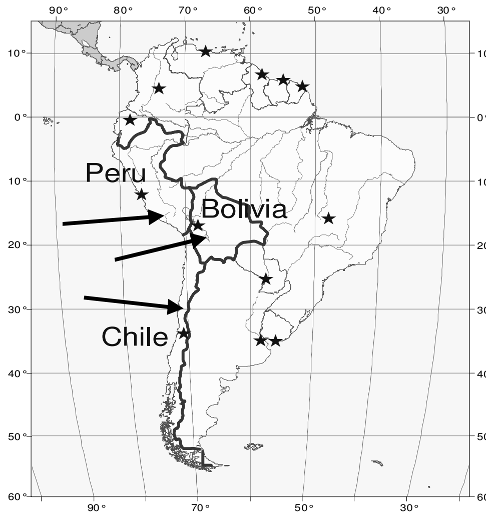
Introduction

The FP6 project CAMINAR has the general aim of contributing to the establishment of policy options, management strategies and technologies for the sustainable management of ecosystems in those river-basins of arid and semi-arid South America which are subject to impacts from mining. This aim will be achieved using Peru, Bolivia and Chile as ‘demonstration’ countries, through realisation of the following objectives: establish forums for dialogue on the ecological and water resources impacts of mining in arid/semi-arid river basins (at both national and regional levels); critically evaluate the effectiveness of existing regulatory strategies for mining in arid/semi-arid areas through studies of selected river-basins in the demonstration countries; develop guidelines for integrated water resources and ecosystem management in arid/semi-arid zones of South America with particular emphasis on mining impacts; develop decision support tools to facilitate participatory water management planning; and derive a set of principles for future policy development and implementation to protect fragile ecosystems and dependant human communities in arid/semi-arid regions.
The project will use as demonstrations catchments (Figure 1) the River Chili basin (Peru), the Lake Poopo and Uru Uru basin (Bolivia) and the River Elqui basin (Chile). In this paper we present results on river basin characteristics, pressures and issues from the three case studies.

Peru

The Chili river basin is a regulated catchment that is located in the Southwest of Peru in the departments of Arequipa, Cusco, Puno and Moquegua, between 15º 20'–16º 38' S and 71º 00'–72º 02' E, and covers an area of 13.609 km^2, between 0 and 6.055 masl. The monthly average temperature in the river basin fluctuates between -1ºC in the high parts, and 17.7ºC in coastal Pampas; in general the temperature diminishes with the altitude. The precipitation ranges from near 0 mm in the low part of the river basin to 710 mm in the Pañe at 4.254 masl; in general the precipitation increases with the altitude. The evaporation varies from 1.300 mm/year in the high part of the river basin (4.600 masl), to 3.066 mm/year in Characato (2.500 masl).

Figure 1 *Location of the three demonstration catchments*



The main economic activities of the river basin are services, agriculture and cattle farming, manufacturing, construction and mining. In the river basin 18.230 ha are used for permanent agriculture, mainly alfalfa grassland, and 11.841 ha for transitory cultures, predominantly onion, garlic and vegetables. The main cattle activities are milk cattle at lower and medium altitudes, and the raising of South American camelidaes (lamas) for fiber production and meat in the high parts of the basin.

At the moment, the most important conflict regarding water availability is the allocation of water between hydropower, that needs 24 m^3/s to use all its installed generation capacity, and drinking and irrigation water, that only require 10 m^3/s. The demand of water for direct human consumption of the urban population (800.000 habitants) is of 1.500 l/s (85% superficial water and 15% ground water), 100 l/s are used by mining, and 50 l/s by the industry. If the maximum demands of water for hydroelectricity were met, the water stored in the reservoirs of the river basin would be exhausted in September of every year. The increase of the demand of water for the population, the extensions of the agricultural area and the expansion of the mining and industrial activities will surpass the capacity of storage of the river basin in 2010 (AUTODEMA – INADE, 2001).

To date, mining-related problems in the area are minor. The biggest mine of the region, Cerro Verde, produces copper using good practices. They have financed with EGASA, a hydropower company, the construction of the Pillones reservoir (80 hm^3, 1.6 m^3/s), and have currently allocated less than a third of its capacity for their operation, the remainder being available for other uses. The mine has been working oxidized ore, which requires little water. No significant water contamination from the mine has been reported to date. However, the mine is preparing to switch to primary sulphide-bearing ore, which has raised concerns amongst stakeholders due to its higher water consumption and increased environmental risks.

The waters are of good quality, and apt for human consumption and irrigation, from the high part of the river basin to the city of Arequipa. There, domestic and industrial wastewaters from the city contaminate waters of the Chili river substantially with organic matter and coliforms. Further downstream, the Chili mixes with the Vitor River that has a high salinity. The agricultural activity, that mainly uses irrigation by flooding, produces excesses infiltration water that contains agrochemicals and dissolves salts of the subsoil. Due to these two factors, waters of the Chili river downstream of Arequipa city, and the Vitor river in almost all its length, are not suitable for human or agricultural use (AUTODEMA – INADE, 2001). The main problem of the river is the contamination by domestic and industrial sewage of the city of Arequipa.

In order to achieve a sustainable use of water in the Chili river basin, it is recommended to greatly increase sewage treatment capacity of Arequipa city, to construct new dams, to change the regulation of the river basin water from the current annual approach to a planning over several years, to implement systems of drip trickle irrigation in the agriculture of the river basin, and to sensitize to the population on the urgency of solving the problems related to water usage and contamination.

Bolivia

The Lake Poopo and Uru Uru basin is located between 17º 30'–19º 50' S and between 66º 30'–69º 00' W, with elevations between 3692 masl and 3950 masl. Politically, it is divided into 16 provinces. The capital Oruro is located at an altitude of 3709 masl. The northern two thirds of the basin are semi-arid, and the southern third is arid (Calizaya Andrés et al., 2006).

The aquatic ecosystems of the lakes Poopó and Uru-Uru are subject to a climatic variability that determines a very drastic instability of the environmental conditions for the biological communities (Lorini, 1993). Moreover, the use for irrigation of water of the Desaguadero river, which feeds the Poopó lake, in addition to the different interbasin diversion programs of the neighboring countries, have modified enormously the natural flow rate that maintained the water level of these lakes (e.g. Garreaud et al., 2003).

This area has an intense mining activity that significantly affects the surface waters in the Poopo lake basin. The northern region of the lake Poopo is affected by the foundries that emit significant amounts of pollutants to the air and water, besides the acid rains caused by sulphur and nitrogen dioxides.

Without exception, all the rivers that drain catchments with mining operations to the Poopó lake are chemically contaminated. The Pazña river has very low pH values (2.6). However, the Poopo river, located between the rivers Huanuni and Pazña, has an alkaline pH. Pazña river displays elevated cadmium, zinc, iron and lead concentrations, but only in the rainy season. The Poopo river has a high arsenic content mainly in the dry period. The arsenic is of geogenic origin (naturally released by the bedrock). Probably the arsenic is As(V), which is the most stable oxidation state in aerobic conditions. The concentrations of heavy metals and arsenic are in many cases 10 to 100 times above the permitted values. Similar ranges are observed for the suspended solids. Most rivers of the lake Poopó and Uru Uru basin have high sodium, sulphate and chloride concentrations, and mean concentrations of 0.5 µg/L of cadmium, 0.3 µg/L of lead and 4.6 mg/L of arsenic. Only the rivers Huaya Pajchi and Huancane do not only display any major element nor heavy metals above the permissible limits for any type of use. The shallow aquifers show medium salinity and low sodium concentration, but high concentrations of arsenic, cadmium, zinc and copper. The river and lake sediments have high concentrations of lead, cadmium and arsenic.

Therefore, the waters of the lakes Poopó and Uru Uru are not suitable for any use. Regarding the rivers in the basin, only the Huancane and Huaya Pajchi rivers can be used for irrigation without restriction, while the other rivers can be used for irrigation only with restrictions, depending on the type culture and the season.

The extreme climatic variability plus the mining contamination with heavy metals in the water bodies and sediments seriously affect biological diversity. There is also an enormous threat for human health, especially due consumption of fish such as the *Pejerrey* by the ethnic groups of the *Urus Muratos*. This danger is also being ignored by the regional authorities and fishery organizations, who are currently trying to promote intensified fishing as a means to improve the conditions of life of the residents.

Chile

The Elqui River watershed is an arid basin located in the Coquimbo Region, North Central Chile, in the so-called "Norte Chico" area. It extends between 29º 27'–30º 34' S and 71º 22'–69º 52' W, covering an area of ca. 9,700 km^2. The geology of the basin comprises Lower Palaeozoic to Upper Tertiary, calco-alkaline plutonic and volcanic rocks (lava flows and pyroclastic rocks), with some marine sedimentary intercalations of Jurassic and Lower-Cretaceous age. These formations are highly fractured and those of Cretaceous and Tertiary age present abundant mineral deposits (Cu, Au, Ag, Mn, As) and hydrothermal alteration zones. (Oyarzun, 1998, Oyarzun 2000).

The climate of the Elqui basin displays a periodic water scarcity, as result of the variability in precipitation, which is manifested in long and persistent dry periods. However, the El Niño phenomenon has a great influence on the climatic oscillations in this area, causing extreme wet and dry periods in El Niño and La Niña years, respectively. Annual rainfall amounts to 90–100 mm, and tend to be concentrated in April-September, the autumn–winter period (Vuille and Milana, 2007).

Despite the arid and variable climatic conditions, the Elqui basin (like other basins of the arid belt) has undergone an important development of the agricultural and agro-industrial activities, which are supported by an extensive system of irrigation channels (over 117 channels of almost 750 km length), which allow irrigated agriculture on over 13,000 ha. In addition, the mild climate, alluring landscapes, large and white sand beaches and other regional appeals have attracted a large and rapidly growing population to the La Serena-Coquimbo conurbation, which attained 322.562 inhabitants in 2003 (ca. 88% of the total population of the basin). In the summer tourist season, population increases even more, coincidental with the driest time of the year. Mining has also been historically important in the area, and the high metal prices of the last years, in particular for Cu and Au, have fostered a re-activation of the mining industry.

Three mining districts in the Elqui basin are of major importance, although they differ in terms of the type and relevance of its polluting effects on the watershed: the Andacollo, Talcuna, and El Indio districts. In addition to these districts (and mining operations), a large number of ore deposits (Cu, Ag, Au ores, with minor contents of Zn, Pb, As, etc.) were mined during the 19th and 20th centuries. These operations have left a heritage of barren and low-grade material waste piles, tailings from the sulphide concentration processes, acid (Cu) and alkaline cyanide (Au) bearing leach pile wastes, and minor residues of mercury related to gold recovery. Also, the cavities left by mining collect groundwater, enhancing water-rock interaction, the transport of soluble salts containing heavy metals, and in some cases, the generation of acid drainage. The case of the El Indio mine and its closure plan has shown that acid drainage generation is a problem that extends way beyond the closure of the mine (Galleguillos et al. *In press*).

Major difficulties have risen in El Niño years due to flash floods that erode and transport abandoned tailing deposits and wastes and by the permanent worries of the agricultural sector and authorities due to contamination problems provoked by mining activities. Also, non El Niño-related tailings spills have occurred even recently as a consequence of bad or irresponsible practices.

Another important issue in the catchment is related to increasing stresses for the use of water by the mining sector and other important economic and social activities developed in the Elqui basin. On the one hand, the Chilean government endeavours to transform Chile into a world-leading food producing country. On the other hand, if the high prices of metals (Au, Cu) remain for the coming years, there will be an increasing interest in mining exploration and the start of new projects or the expansion of current ones. This situation will likely add additional pressure on the mining sector, regarding operating processes and waste management.

Thus, the combination of all these factors (aridity, contamination, water competing economic activities) are starting to create problems at the watershed level that must be addressed before it is too late.

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