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Geogenic arsenic and other trace elements in the shallow hydrogeologic system of Southern Poopó Basin, Bolivian Altiplano

Mauricio Ormachea Muñoz[a,b,*], Hannes Wern[a], Fredrick Johnsson[a], Prosun Bhattacharya[a], Ondra Sracek[c], Roger Thunvik[a], Jorge Quintanilla[b], Jochen Bundschuh[a,d]

[a] KTH – International Groundwater Arsenic Research Group, Division of Land and Water Resources Engineering, Department of Sustainable Development, Environmental Sciences and Engineering, Royal Institute of Technology (KTH), Teknikringen 76, SE-100 44 Stockholm, Sweden
[b] Laboratorio de Hidroquímica, Instituto de Investigaciones Químicas, Universidad Mayor de San Andrés, 303, La Paz, Bolivia
[c] Department of Geology, Faculty of Science, Palacký University, 17. listopadu 12, 771 46 Olomouc, Czech Republic
[d] Faculty of Engineering and Surveying, University of Southern Queensland, Toowoomba, Queensland 4350, Australia

HIGHLIGHTS

- Groundwater used as drinking water has elevated concentrations of arsenic and boron.
- Sediments are potential sources of arsenic and boron in shallow groundwater.
- Fe-oxides and hydroxides are important absorbents of arsenic.
- Multiple geochemical processes drive mobilisation of arsenic in groundwater.

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ABSTRACT

Environmental settings in the southern area of Lake Poopó in the Bolivian highlands, the Altiplano, have generated elevated amounts of arsenic (As) in the water. The area is characterised by a semiarid climate, slow hydrological flow and geologic formations of predominantly volcanic origin. The present study aimed at mapping the extent of the water contamination in the area and to investigate the geogenic sources and processes involved in the release of As to the groundwater.

Ground- and surface-water samples were collected from 24 different sites, including drinking water wells and rivers, in the southern Poopó basin in two different field campaigns during the dry and rainy seasons. The results revealed variable levels of As in shallow drinking water wells and average concentration exceeding the WHO guidelines value. Arsenic concentrations range from below 5.2 μg/L (the detection level) to 207 μg/L and averages 72 μg/L. Additionally, high boron (B) concentrations (average 1902 μg/L), and high salinity are further serious concerns for deteriorating the groundwater quality and rendering it unsuitable for drinking. Groundwater is predominantly of the Na–Cl–HCO_3 type or the Ca–Na–HCO_3 type with neutral or slightly alkaline pH and oxidising character. While farmers are seriously concerned about the water scarcity, and on a few occasions about salinity, there are no concerns about As and B present at levels exceeding the WHO guidelines, and causing negative long term effects on human health.

Sediment samples from two soil profiles and a river bed along with fourteen rock samples were also collected and analysed. Sequential extractions of the sediments together with the calculation of the mineral saturation indices indicate that iron oxides and hydroxides are the important secondary minerals phases which are important adsorbents for As. High pH values, and the competition of As with HCO_3 and dissolved silica for the adsorption sites probably seems to be an important process for the mobilisation of As in the shallow groundwaters of the region. Continuous monitoring and expansion of monitoring systems are necessary prerequisites for better understanding of the pattern of As mobilisation in the Southern Poopó Basin.

* Corresponding author at: KTH – International Groundwater Arsenic Research Group, Division of Land and Water Resources Engineering, Department of Sustainable Development, Environmental Sciences and Engineering, Royal Institute of Technology (KTH), Teknikringen 76, SE-100 44 Stockholm, Sweden. Tel.: +46 8 790 8136; fax: +46 8 20 89 46.
E-mail addresses: ormachea@kth.se, maurormache@gmail.com (M. Ormachea Muñoz).

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1. Introduction

Water contamination, either from natural or anthropogenic sources is an issue of major environmental concern with severe social impact in many countries around the world. A widespread threat comes from geogenic As, often referred to as a "silent" toxin [1] because the adverse effects of As toxicity is manifested after a long time. An increasing number of geographical areas throughout the world are reported to have elevated levels of As in drinking water, with the potential to cause severe chronic health effects in humans such as neurotoxicity, cardiovascular diseases and increased risks of developing cancer [2–4]. High-As groundwater areas are well known in Argentina, Chile, Mexico, China, the US and Hungary [5,6]; as well as in the State of West Bengal in India, Bangladesh and Vietnam [7–11]. A total of about 150 million people are estimated to be affected worldwide with a prospect outgrowing as new contaminated areas are constantly discovered [12].

In Latin America (LA) many regions are known to have toxic levels of As in the groundwater [11,13]. While some of these areas were discovered early, in Argentina already in 1917 [14], most areas were discovered in recent years. Current investigations in the region were performed following the intensified research set off by the discovery of vast contamination in South and southeastern Asia [11,13].

In several LA countries viz. Argentina, Bolivia, Chile, Peru, As contamination is caused by geogenic As originating from sulphide-rich minerals formed by the extensive magmatic and hydrothermal activities, and extensive volcanism along the Andean mountain ranges leading to the deposition of volcanic ash in the region. Bulk of As is mobilised in groundwater due to the dissolution of volcanic glass in loess sediments in the Pampean region [6,11,15]. Arsenic is released in groundwater in connection with human activities such as mining but foremost due to natural dissolution and rock weathering [11].

Investigations on combined natural contamination of B, As, Li, and other trace elements in drinking water and their impact on the population were carried out in some countries of LA [16–18]. In Bolivia, Banks et al. [15] revealed the presence of high concentrations of B and As in surface waters of the catchment areas of the salt plains, nevertheless high concentrations of As and B in drinking water still is an issue of major concern in the Bolivian Altiplano (BA).

One of the affected regions is found in the BA where the recent period of dry climate has struck to water supply reservoirs hard. The country has a weak economy and is poorly prepared to tackle the consequences of the current decline of freshwater resources. Less rainfall, shrinking glaciers and contamination of natural waters burden the already struggling population of the Altiplano, particularly during the stretched-out dry period from April to November. During this season, many rivers dry up and groundwater becomes the only available source of freshwater in the region for drinking purposes.

Living conditions are especially harsh in the Department of Oruro, one of the poorest administrative districts in Bolivia [19]. This province, situated in the central Altiplano, has both groundwater and several rivers contaminated with As. This contamination is partly caused by the extensive mining activity in the area from which residues leach to adjacent rivers and subsequently to the main recipient in the region, the Lake Poopó [20–22]. The lake, once important for its fishing industry, is now practically dry due to decreased rainfall in recent years and is also heavily polluted, particularly with As and heavy metals [23].

Although the Department of Oruro is a major mining district there are no active mines present in the studied area around the Southern Poopó basin, still groundwater with high As concentration has been discovered in this region as well [20–22]. The La Amistad mine located 8 km southwest of Sevaruyo (Fig. 1) was a very small one with copper sulphides and carbonates mineralisation in the sandstones, it has never been exploited for industrial production and has been closed for more than 40 years [24]. Arsenic concentrations measured in drinking water wells in this area by far exceed the WHO guideline value of 10 μg/L. It is therefore important to identify the major processes causing this contamination which can help find potable freshwater sources in the region.

The present study deals with the assessment of surface- and groundwater quality, their physicochemical characterisation and their relationship with the distribution of As and other trace elements in the southern area of the Lake Poopó. This study focuses on (a) the determination of basic hydrogeochemical characteristics of surface- and groundwater and (b) the identification of the major sources and processes behind the geogenic As contamination of drinking water in the region. This understanding would be crucial for the development of suitable remediation measures to help the local population manage their drinking water resources.

2. Study area

2.1. General description

The study area is located in the Department of Oruro to the east of the BA between 19°7′40″ S and 67°3′44″ W (Fig. 1). It encompasses an area of 1400 km^2 with an elevation range between 3700 and 3900 m a.s.l. [25]. The area is essentially a flat plain situated at the centre, which is enclosed to the north by the Lake Poopó, to the east by the mountain range Cordillera Oriental, to the west by the Marques River, and to the south by the volcanic plateau of Los Frailes.

The extent of the study area was chosen based on previously reported high As concentrations [20–22] around a 25 km long belt stretching along the southern shores of the Lake Poopó, between the villages of Pampa Aullagas and Condo K (PACK belt) (Fig. 1). The boundary of the study area was drawn to include the upstream catchment in order to account for all possible sources behind the high concentrations in the PACK belt.

At the time of the official census in 2001 the area had 7300 inhabitants, and it is estimated that now there are about 10,000

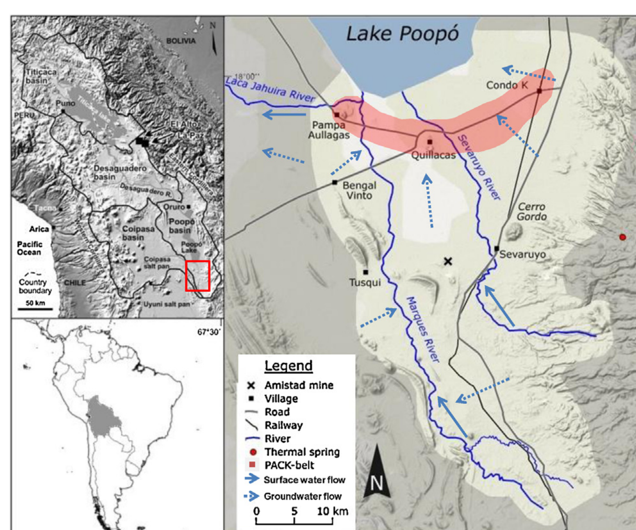

Fig. 1. Map of the Altiplano with major basins and physiographic features (upper left), location of Bolivia (lower left) and map of the study area (right), located to the south of Lake Poopó. The area of natural arsenic contamination more important is shaded in red, here called the PACK-belt. Segmented arrows shows estimated major groundwater flow directions. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)