



Review article

Perchlorate contamination in Chile: Legacy, challenges, and potential solutions

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ARTICLE INFO

Keywords:

Perchlorate
Chile
Atacama Desert
Caliche
Perchlorate-reducing bacteria

ABSTRACT

This paper reviews the unique situation of perchlorate contamination in Chile, including its sources, presence in environmental media and in the human population, and possible steps to mitigate its health impacts. Perchlorate is a ubiquitous water contaminant that inhibits thyroid function. Standards for drinking water range from 2 to 18 $\mu\text{g L}^{-1}$ in United States and Europe. A major natural source of perchlorate contamination is Chile saltpeter, found in the Atacama Desert. High concentrations of perchlorate have presumably existed in this region, in soils, sediments, surface waters and groundwaters, for millions of years. As a result of this presence, and the use of Chile saltpeter as a nitrogen fertilizer, perchlorate in Chile has been found at concentrations as high as 1480 $\mu\text{g L}^{-1}$ in drinking water, 140 $\mu\text{g/kg}^{-1}$ in fruits, and 30 $\mu\text{g L}^{-1}$ in wine. Health studies in Chile have shown concentrations of 100 $\mu\text{g L}^{-1}$ in breast milk and 20 $\mu\text{g L}^{-1}$ in neonatal serum. It is important to acknowledge perchlorate as a potential health concern in Chile, and assess mitigation strategies. A more thorough survey of perchlorate in Chilean soils, sediments, surface waters, groundwaters, and food products can help better assess the risks and potentially develop standards. Also, perchlorate treatment technologies should be more closely assessed for relevance to Chile. The Atacama Desert is a unique biogeochemical environment, with millions of years of perchlorate exposure, which can be mined for novel perchlorate-reducing microorganisms, potentially leading to new biological treatment processes for perchlorate-containing waters, brines, and fertilizers.

1. Introduction

Perchlorate (ClO_4^-) is an ubiquitous water contaminant, of environmental concern due to its inhibitory effect on mammalian thyroid function (Srinivasan and Sorial, 2009). Its high solubility, stability, and low sorption affinity make perchlorate highly mobile in aqueous systems, and also makes it a challenge to treat.

Perchlorate contamination mainly results from the disposal of synthetic perchlorate to the subsurface, a common practice prior to the existence of more stringent environmental regulations (Backus et al., 2005; Motzer, 2001). It also may result from the use of explosives, fireworks, fertilizers and other perchlorate-containing products. These anthropogenic perchlorate sources, as well as exposure pathways, are fairly well characterized.

Perchlorate also is formed by natural photochemical processes (Dasgupta et al., 2005; Kang et al., 2006, 2008; Rao et al., 2010). While these natural formation processes result in the widespread presence of perchlorate in the environment, the levels are typically below those thought to present a health concern. However, there are a few cases

where natural perchlorate exists at very high concentrations. One of the most notable is in the Atacama Desert in Chile, where perchlorate exists in saltpeter deposits at concentrations up to the g kg^{-1} range (Jackson et al., 2015). The potential threat of these natural sources is not well understood, and treatment technologies relevant to Chile also are unknown.

This review provides an overview of perchlorate in the environment in Chile. We discuss how perchlorate in soils has resulted in contamination of different matrices, such as drinking water and food, and review evidence of human exposure. We discuss health effects and the need for perchlorate risk assessments in Chile. Finally, we suggest future research to address perchlorate in the environment in Chile. Chile may serve as a model for the few other locations with similar conditions. Chile also may provide a unique, natural “laboratory” for research on perchlorate-reducing microorganisms.

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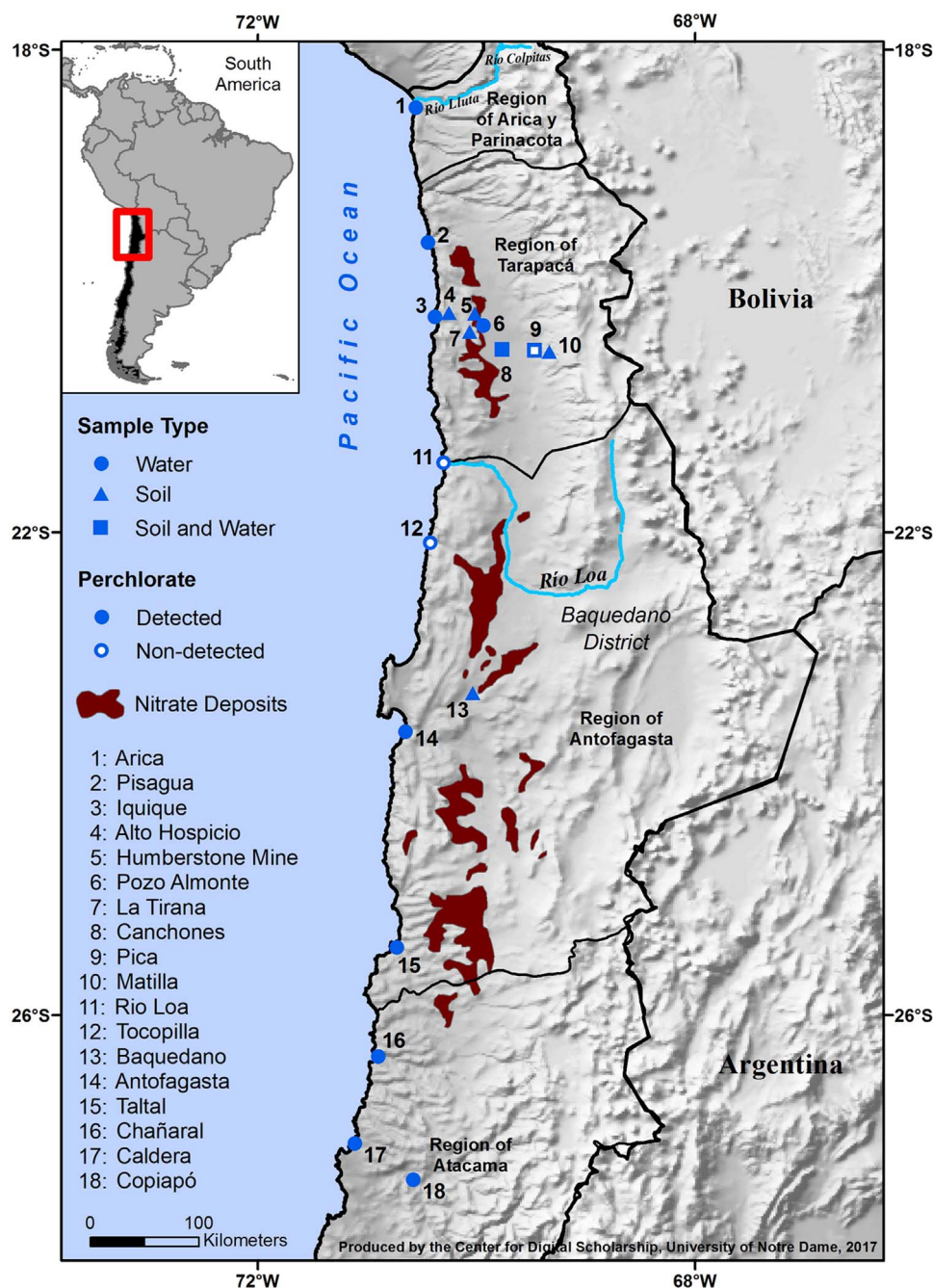


Fig. 1. Location of natural perchlorate found in Atacama Desert, Chile. Presence of perchlorate in different matrices from cities of the Atacama Desert and places near the nitrate deposits. Adapted from Ericksen (1983). In location 9, perchlorate was below detection in the soil sample ($< 40 \mu\text{g}/\text{kg}$), but it was detected in the water sample. For locations 11 and 12, the detection limits were not defined.

2. Background

2.1. Sources of perchlorate

Due to its high oxidization potential, perchlorate has been synthesized for use in numerous applications, such as rocket fuels, explosives, fireworks, air bags, munitions, signal flares and in a wide range of industrial products (Backus et al., 2005; Motzer, 2001). As a result of its widespread use, perchlorate contamination in United States (U.S.), Europe, and other industrialized countries is widespread (Smith et al., 2001).

It has been shown that perchlorate can be naturally formed through serial reactions in the atmosphere involving UV exposure, ozone

oxidation, and/or electrical discharges such as lightning (Dasgupta et al., 2005; Kang et al., 2006, 2008; Rao et al., 2010). After it forms in the stratosphere, it can reach soils through wet or dry deposition. In wet deposition, perchlorate dissolves into moisture droplets and is removed by precipitation. When perchlorate-containing precipitation reaches the ground, perchlorate may be deposited in soils. However, given its high solubility and poor sorption properties, it is readily transported to surface water or groundwater sources (Rajagopalan et al., 2009; Rao et al., 2007). Dry deposition can occur in the form of eolian dust, atmospheric aerosols and gases (Andraski et al., 2014). These processes are thought to account for the trace perchlorate levels found in many environments. It may also explain high perchlorate concentrations in arid environments, such as the Atacama Desert, as there is not enough

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