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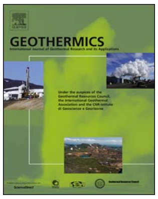

Heavy metal sources and anthropogenic enrichment in the environment around the Cerro Prieto Geothermal Field, Mexico

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ABSTRACT

The Cerro Prieto Geothermal Field (CPGF) is the biggest in Mexico, fourth worldwide, and it started electricity generation in 1973. This work correlates heavy metals in environmental samples, tracing the geothermal energy fingerprint from water an air, into soil and plants around CPGF. By X-Ray Fluorescence, we identified heavy metals (Cr, Mn, Pb, Pd, Ru, V and Zn) from other different sources than the CPGF. Enrichment factors of soils suggest that Sb, Cl and Na are naturally enriched in the zone, and S mainly from geothermal sources in air, enriches leaves of *Allenrolfea occidentalis*.

1. Introduction

The study of the distribution and accumulation of heavy metals is of great interest because of negative consequences on human health and on the environment (Järup, 2003) due to their potential bioaccumulation in living organisms and their lack of biodegradation capacity (Duruibe et al., 2007). To understand biogeochemical cycles of metals in certain areas, studies of the environment should include chemical elements from the hydrosphere, lithosphere, biosphere and atmosphere, as well as anthroposphere to evaluate the human impact.

Whereas soil is the main source of biologically active elements supporting plant and animal life, and can be a source of heavy metals, depending on its geological nature, (Sharma and Aghrawal, 2005), water serves as vehicle for the dissolution and transport of metals (Schnoor, 1996). Meanwhile, the atmosphere also can transport heavy metals as particulate matter, these can be deposited at great distances from their initial source (Outridge et al., 2005; DeVries et al., 2013). Plants have a natural capacity to selectively accumulate heavy metals and nutrients derived from soil, water and air, and often are used as Bio-indicator in pollution monitoring (Meers et al., 2008; Simon et al., 2011).

Environmental pollution by heavy metals is due to several processes, whether natural as weathering, or anthropogenic, related to mining, metallurgy, agriculture, industrial activities, burning of fossil fuels and vehicular emissions. Geothermal power plants are environmentally attractive since they employ a renewable energy source. Compared with other energy sources, such as natural gas or fossil fuels, geothermal energy is considered one of the cleanest, even though it releases large volumes of fluids (liquids and gases) from the subsoil (Moore and Simmons, 2013). Geothermal activities can also release heavy metals that can leach into groundwater (Kagel et al., 2005), although dissolved chemicals in wastewater depend on the geochemistry of the reservoir and operating conditions of each power plant and can vary widely between geothermal fields (Hunt, 2012). Geothermal gases are discharged to the atmosphere from different punctual sources: silencers, cooling towers, pipe leaks, vent stack, among others. Among these gases, hydrogen sulfide (H_2S) is upmost concern, since it could represent a health risk at relatively low concentrations. Once in the atmosphere, it changes to sulfur dioxide (SO_2), favoring the formation of small acid particles that can be absorbed by the bloodstream and cause heart and lung diseases (NRC, 2010). For H_2S, the WHO recommends a maximum exposure of $150\,\mu g\,m^{-3}$ in 24 h (WHO, 2000). In Iceland, where geothermal energy represents 29% of the electricity generation (Orkustofnun, 2014), the regulation limit of H_2S is $50\,\mu g\,m^{-3}$ average in a 24 h floating period (Hansell and Oppenheimer, 2004), and in Mexico, where geothermal energy represents 5.52% of the electricity generation (SENER, 2016) the limit of H_2S is a remarkable $15000\,\mu g\,m^{-3}$ in a shorter period of 8 h but the regulation is only applicable to workers at the site (NOM-010-STPS-1999).

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The Cerro Prieto region is located in the south of Mexicali Valley, Baja California (BC), Mexico, inhabited by over one million people. In this municipality, 211,000 ha are used as irrigated farmland, and some industries are present mainly from the metallurgy sector. Located in Cerro Prieto, is the biggest geothermal power plant of Mexico, named Cerro Prieto Geothermal Field, which started operations in 1973, it currently produces up to 4028.27 GWh (SENER, 2016). The water that drains through this area flows from north to south with agricultural and domestic wastewaters and variable amounts of unmanaged flows (Cohen, 2002; Nelson et al., 2013).

Peralta et al. (2013), measured meteorological parameters and environmental concentrations of H_2S, criteria pollutants and non-condensable gases from vent stacks at Cerro Prieto Geothermal Field (CPGF). They found as a main conclusion that measured air pollutants never exceeded local environmental standards (based on occupational exposure). Measured gases linked to automotive exhaust emissions were more significant than gases from CPGF. Environmental determinations and dispersion modeling showed a radius of 5 km around CPGF continuously covered by H_2S.

Recent studies about groundwater quality in the agricultural area adjacent to CPGF, evaluated the influence of the geothermal field in the water chemistry. These studies found high Cl concentrations attributed to chloride-enriched water from channels used for irrigation. Besides As, Cd, Cr, Cu, Hg and Pb were found in concentrations within Mexican irrigation water standards. No elements related with geothermal brines and toxic metals and metalloids shown the influence of CPGF (Armienta et al., 2014).

Previous studies have been focused on the presence and distribution of heavy metals in the water or air, little attention has been put on soil and plants (Mutia et al., 2016). In addition, it remains unclear how those heavy metals are correlated and if they are from anthropogenic sources. In this study we correlated heavy metal concentrations in environmental samples (soil, water, vegetation and air) around CPGF, Mexico to identify possible sources and quantify anthropogenic enrichment. These results will contribute to the understanding of biogeochemical cycles of heavy metals in the region of Cerro Prieto, Mexicali, Mexico.

2. Study area

This study was carried out in the vicinity of Cerro Prieto Geothermal Field (CPGF) in Mexicali Valley, BC, Mexico (Fig. 1). The CPGF is located in northern Mexico in an active rift basin developed into sands and shales. The geothermal fluids at Cerro Prieto are contained in sedimentary rocks (Tertiary sandstones) whose original cement has been replaced by hydrothermal minerals such as quartz, calcite, chlorite, epidote, prehnite, etc. The heat source is a regional thermal anomaly resulting from the thinning of the continental crust at the basin bottom (Hiriart and Gutiérrez-Negrín, 2003). This geothermal field is located in one main area of 74 km^2 where there is an evaporation pool that occupies around 18 km^2. This evaporation pool was originally built to produce ammonia nitrogen in 1985, but it never worked out because of high costs associated to this process. Then, CFE (Electricity Federal Commission) used this facility as an evaporation pool, where geothermal brines from cooling towers and residual fluids from geothermal wells are disposed. These geothermal brines enter the pool at a temperature between 50 and 30 °C. The pool has a maze arrangement, this permits the geothermal brine to cool down in outside layers up to ambient temperature (Miranda-Herrera, 2015).

The Irrigation District 014-Río Colorado intersects the agricultural district of the Mexicali Valley, BC that is subdivided in 22 irrigation modules and drains into the Gulf of California. The Reforma channel and Morelos Dam receive 90% of the Colorado River flow and the water is then distributed to the irrigation modules through a series of lined and unlined channels (Carrillo-Guerrero et al., 2013).

It is reported that the water from the Colorado River reaches an average concentration of 1000 mg L^{-1} of total dissolved solids, where highly soluble salts are present. The Colorado River in its trajectory (2300 km) transports an average water volume of 18,248 Mm^3, carrying in solution around 9 Mt of salts. This represents for each m^3 of water that is applied to the soil during the irrigation process, that an average of 1 kg of salt is incorporated to the soil. Eventually this salt has to be removed from the soil profile; otherwise it will lead to a rapid soil salinization and as consequence, will cause a progressive reduction in their productive capacity (Glenn et al., 1998; SEDAGRO, 2009). In this zone, the soil salinization is also attributed to a mineralization in the aquifer detected with the increase of dissolved total solids in the well

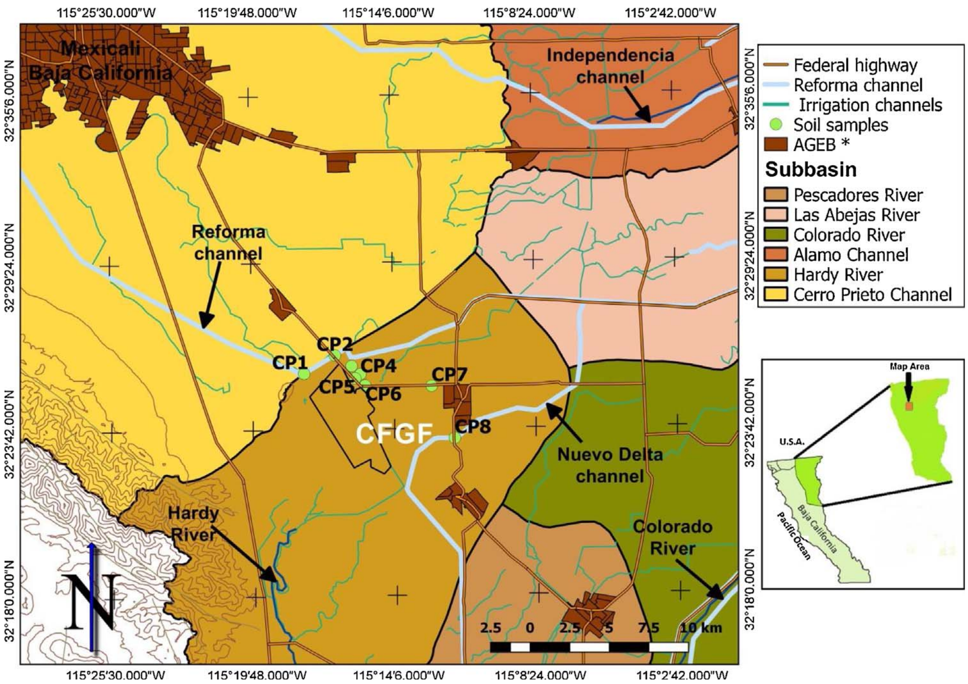

Fig. 1. Map of the hydrology of the Mexicali Valley, Baja California (BC), Mexico. Inset shows the location of the study area within BC. CP- Sampling sites in Cerro Prieto *[AGEB: Basic Geostatistical Populated Area, it constitutes the fundamental unit of the national geostatistical framework with a selection of main concepts of the population census (INEGI, 1992)].