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Groundwater quality and geothermal energy. The case of Cerro Prieto Geothermal Field, México

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ABSTRACT

The influence of the Cerro Prieto Geothermal Field (CPGF) on groundwater quality of the close-by agricultural area was evaluated by means of chemical and isotopic determinations. According to irrigation standards, concentrations of As, Cd, Pb, Crtot, Cr(VI), Cu, Cd, Hg, B in agricultural wells showed the suitability of the water for irrigation. Iron was below irrigation limits in all but one well. However, chloride levels were above those limits in 83 out of 87 collected samples. Isotopic determinations of δ^2H, $\delta^{18}O$, $\delta^{34}S$, $\delta^{13}C$, and spatial concentration trends of elements related with geothermal brines and toxic metals and metalloids did not indicate an influence of the CPGF to groundwater in the nearby agricultural area. Isotopic values of δ^2H, $\delta^{18}O$ showed the occurrence of evaporation processes and infiltration of canal's irrigation water to geothermal water reservoirs and to groundwater in the agricultural zone. High chloride concentrations might be associated with these processes.

1. Introduction

Geothermal energy has been claimed to be one of the most environmental friendly energies [1,2] mainly because of its lower emission of greenhouse gases [3–5] and especially before the world spread use of solar and wind energies. In spite of providing less MW than other energy supplies, it is still relevant, with an installed capacity of 10715 MW in 2010 [5]. However, geothermal power plants have been pinpointed as pollution sources, mainly owing to the release of H_2S and other toxic chemicals usually emanated in geothermal zones [6–9]. Nevertheless, although some studies have reported pollution of water bodies from geothermal plants [10,11], their impact to the quality of waters and soils has been brought up less. Toxic elements like Cd, Hg, As, Cd, Mn, F and boron are usually enriched in geothermal fluids [12–18]. These elements may pollute the environment through spills and interaction of deep geothermal brines with shallow aquifers and surface waters.

In México, electrical energy is mainly provided by thermal plants (oil, natural gas and charcoal) with about 75% of the generation capacity in 2010 [19]. Yet, Mexico is the fourth ranked country generating geothermal energy with an installed capacity of 958 MW [5]. Furthermore, the geothermal power plant of Cerro Prieto, located northwest of the country (Fig. 1) is the second largest of the world, with a capacity of 720 MWe provided by 13 power units [20,21]. While being in continuous operation for almost 40 years, it has been seen by nearby dwellers as an environmental hazard to the surrounding area. However, irrigation with agricultural wash-off water flowing from the USA through the Mexican border collected by a dam, and distributed to an irrigation-canals net, constitutes a contaminating source of shallow groundwater that cannot be overseen. The aim of this work is to evaluate the groundwater quality in the agricultural area adjacent to Cerro Prieto power plant, to determine the actual influence of the geothermal plant in water chemistry, focused on arsenic, heavy metals, fluoride, and boron. To Accomplish this objective geochemical and stable isotopic determinations (^{18}O, D, ^{13}C, ^{34}S) were carried out.

2. Local geological and hydrogeological framework

The study area is located in the Salton Sea Basin which is mostly placed in the North-American territory. The basin was filled with sediments (clay, sands, clayey sands) reaching a thickness of 2000 m [22]. Three sedimentary environments have been identified: fluvial, lacustrine and alluvial.

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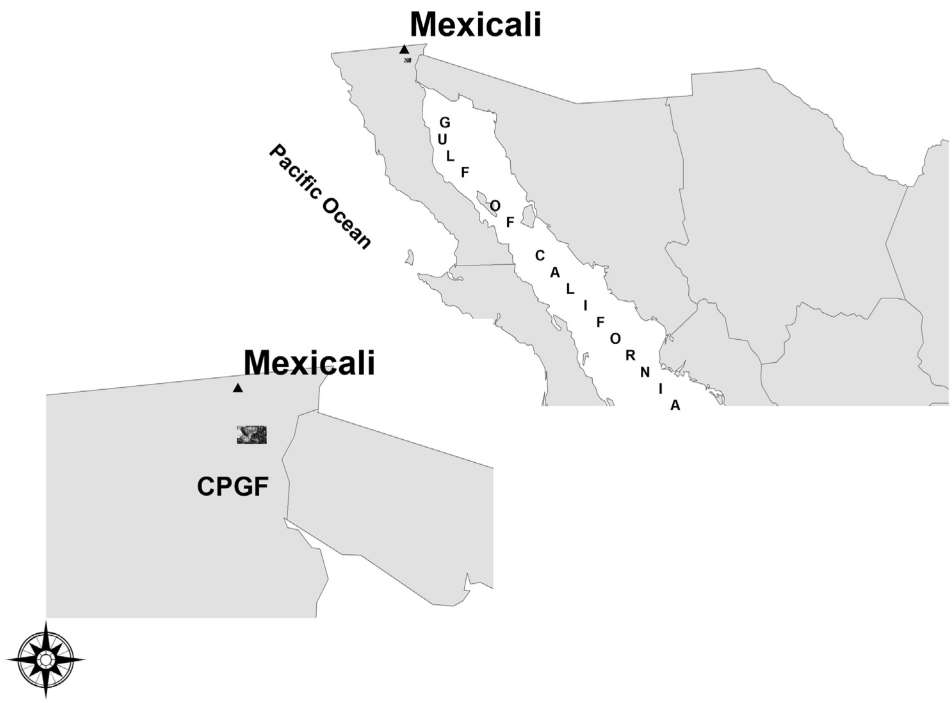

Fig. 1. Location of Cerro Prieto Geothermal Field (CPGF).

The intense regional tectonism has given rise to a complex fault system as the Cerro Prieto, Michoacan and Imperial fault with main orientation NO-SE, and the Volcano and Hidalgo faults perpendicular to the formers [23].

The aquifer system is composed mainly by two units: a shallow phreatic aquifer, and a deep formation. Besides, high salinity and isotope composition in a silt zone suggest the presence of a third aquifer in the southwestern part of the studied area [24] Chloride, bicarbonate and sulfate water types have been identified in the phreatic aquifer, being sodium chloride the most abundant type (chloride concentrations up to 898 mg/L) [24]. The geothermal reservoir is liquid dominated with sodium chloride fluids [25]. High chloride contents (7200–9800 mg/kg) have been measured in drillhole waters [26].

The CPGF is exploiting the deep aquifer, whereas farmers use the shallow one. The confining layer geometry has not been well defined. The fault system might be communicating the three formations. The composition is mainly formed by fine to coarse sediments. Climate is arid (maximum of 41.7 °C in July and minimum of 4.2 °C in January), with an average annual evaporation of 2200 mm/year and precipitation of 55 mm/year [27,28]. The watertable of the shallow aquifer unit is between 4 and 8 m depth. The scarce precipitation, the shallow watertable, and the irrigation scheme indicate that the aquifer system is recharged by infiltrations of the Colorado River, leakages from canals, and irrigation water [29].

The major regional faults, which are believed to reach into the crustal and basement rocks, have been related with important components of ascendant geothermal flow [30], which is mostly exploited by the geothermal plant. The preferential regional flow direction is towards the SW and S in the deep aquifer. Geothermal fluids circulate mostly from east to west [22]. The shallow flow has a direction NE-SW [31], although, the riverbed and the canals exert a local control. However, SW of the evaporation pond within the geothermal field, where some very shallow exploratory wells are located, the flow direction has an opposite direction: SE-N and E-W [29]. Thickness of unconsolidated sediments forming the shallow aquifer ranges from 350 to 400 m west to 2000 m east of the CPGF. An average flow velocity of 1.25–3.7 m/y and hydraulic gradient of 0.042 m/km (for the shallow aquifer) have been estimated in the Valley. A higher hydraulic gradient of 0.4 m/km was calculated according to the piezometric levels in 1995 [25,31]. Cazares [32] informs CONAGUA (National Commission of Water) data: a mean annual aquifer withdrawal of 0.20–0.25 m and a transmissivity range of 0.15 to 0.0775 m^2/s.

3. General hydrogeochemistry

Numerous hydrogeochemical studies have been developed in the Cerro Prieto geothermal area, mainly to accomplish a better exploitation scheme [22,24,25,33–37]. However, there are few publications reporting potentially toxic elements in the geothermal zone or its neighborhood. Being arsenic one of the most toxic elements that may be present in high concentrations in geothermal zones, its presence has been looked for also at Cerro Prieto. A maximum concentration of As from 1.5 to 2 mg/kg was reported in the geothermal wells of the area [13,18,38]. These relatively low contents were explained as a result of water–rock interactions in a sedimentary reservoir [18]. Mazor and Mañon (1979) [34] based on 750 chemical analyses of 30 geothermal wells determined that concentrations of CI, Na, K, Li, Ca, B, HCO_3^- and SiO_2 vary by a factor of two among wells. They also found positive correlations between chloride and Na, K, Li, Ca, B and SiO_2. Chloride behaves as a conservative ion while K and SiO_2 show a reactive pattern that varies with temperature. Mercado (1970) [33] identified the Na/K molar ratio as a good indicator of hydrothermal activity in the Cerro Prieto Geothermal Field (CPGF). He concluded that wells with a Na/K value of 6 correspond to temperatures of 370 °C while those with a ratio of 16 correspond to a lower temperature of 160 °C. Portugal et al. (2005) [24] based on chemical and isotopic analyses identified three hydrogeochemical