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Decreased waterborne pathogenic bacteria in an urban aquifer related to intense shallow geothermal exploitation

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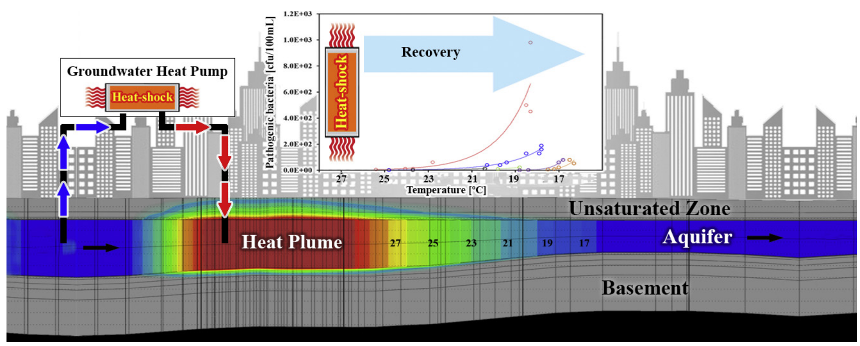
HIGHLIGHTS

- Microbial contamination of groundwater is evaluated in relation to geothermal activity.
- A decrease in waterborne pathogenic bacteria is found within aquifer heat plumes.
- A heat-shock affecting bacteria followed by a recovery pattern is identified.

GRAPHICAL ABSTRACT



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ABSTRACT

The implications of intensive use of shallow geothermal energy resources in shallow urban aquifers are still not known for waterborne pathogens relevant to human health. Firstly, we hypothesized that waterborne enteric pathogens would be relatively increased in heated groundwater plumes. To prove this, microbiological sampling of 31 piezometers covering the domain of an urban groundwater body affected by microbiological contamination and energetically exploited by 70 groundwater heat pump systems was performed. Mean differences of pathogenic bacteria contents between impacted and non-impacted monitoring points were assessed with a two-tailed independent Student's *t*-test or Mann-Whitney U and correlation coefficients were also calculated. Surprisingly, the results obtained revealed a significant and generalized decrease in waterborne pathogen contents in thermally impacted piezometers compared to that of non-impacted piezometers. This decrease is hypothesized to be caused by a heat shock to bacteria within the heat exchangers. The statistically significant negative correlations obtained between waterborne pathogen counts and temperature could be explained by the spatial distribution of the bacteria, finding that bacteria start to recover with increasing distance from the injection point. Also, different behavior groups fitting exponential regression models were found for the bacteria species studied, justified by the different presence and influence of several aquifer parameters and major, minor and trace elements studied, as well as the coexistence with other bacteria species. The results obtained from this work reinforce the concept of shallow

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geothermal resources as a clean energy source, as they could also provide the basis to control the pathogenic bacteria contents in groundwater bodies.

1. Introduction

Shallow geothermal energy (SGE) configures a low-carbon and cost-competitive energy resource capable of satisfying society's heating and cooling demands (Bayer et al., 2012; Lund and Boyd, 2016). Groundwater heat pump (GWHP) systems constitute one of the main SGE technology and consists of an open loop where groundwater is pumped and passed through heat exchangers located in the surface to be afterwards returned to the groundwater body (Florides and Kalogirou, 2007). In the 2000s and 2010 decades, a number of research studies have focused on the changes in the quality of groundwater affected by the operation of GHPS, including thermal (Banks, 2012; Epting et al., 2013; Galgaro and Cultrera, 2013; Händel et al., 2013; Herbert et al., 2013), geochemical (Abesser, 2010; Bonte, 2015; EPA, 1997; García-Gil et al., 2016b; Garrido Schneider et al., 2016; Park et al., 2015; Saito et al., 2016) and hydraulic impacts (Simpson et al., 1989). Although thermal impacts derived from shallow and deep geothermal activity on indigenous non-pathogenic microorganisms have been extensively studied in controlled column experiments (Bonte et al., 2013; Jesussek et al., 2013; Lienen et al., 2017; Wurdemann et al., 2016) and in the field (Brielmann et al., 2009) to understand biochemical clogging, corrosion and geothermal installations' performance due to temperature-induced changes in the aquifer ecosystem, there is a lack of studies regarding thermal effects induced by SGE exploitation on pathogenic microorganism communities.

Groundwater ecosystems offer vast and complex biotopes for diverse indigenous microbial biocenoses including bacteria, fungi, viruses and protozoa (Griebler and Lueders, 2009). The survival of microbes adapted to the intestinal tract environment of homoeothermic animals within soil indigenous communities is of great concern for public health since several groups of enteric bacteria, viruses and protozoa are commonly recognized as disease-causing pathogens to humans (Buffie and Pamer, 2013; Snow, 1855). Also, non-enteric pathogens such as *Legionella pneumophila*, *Staphylococcus aureus* and *Pseudomonas aeruginosa* need to be controlled, as well as free-living amoebae (Anaissie et al., 2002; Cateau et al., 2014). There is now clear evidence of the vulnerability of unconsolidated and consolidated urban shallow aquifers to microbial contamination (Powell et al., 2003). The Environmental Protection Agency of the U.S. was the first national organization to adopt a drinking water regulation to provide standards describing the maximum allowable levels of various microorganisms in drinking water. The persistence of enteric pathogens in aquatic environments depends on temperature, pH, predation or competition with indigenous microorganisms and other pathogenic bacteria, dissolved organics, attachment to particulates, salts contents and other solutes (John and Rose, 2005; Madigan and Martinko, 2006). Temperature is the crucial physical variable which controls microbial activity. While indigenous microorganisms are adapted to different temperature ranges (psychrophilic, mesophilic and thermophilic microorganisms), enteric pathogens are highly adapted to warm temperatures of approximately 37 °C, closely matching the temperature of warm-blooded animals (West et al., 1991). The existent and increasing anthropic pressure over urban groundwater resources in densely populated areas where sewage contamination is ubiquitous has allowed broadening the transport and survival of sewage-derived microorganisms into groundwater (Rutsch et al., 2008). The relevant release of nutrients and pathogens from leaking sewers, together with an increase in groundwater temperature produced by intensive SGE exploitation may result in a significant increase in pathogen occurrence and counts, which might entail a public health concern.

In this work, we evaluate the occurrence of waterborne pathogenic bacteria, namely coliform bacteria (CB), fecal *streptococci* (*FS*), *Escherichia coli* (*ECo*), *Clostridium perfringens* (*CP*), *Salmonella* spp. (*S*), *Staphylococcus aureus* (*SA*), *Legionella pneumophila* (*LP*) and *Pseudomonas aeruginosa* (*PA*), as well as free-living amoeba to answer the following arising questions: How do the pathogen contents in groundwater change in relation to the thermal plumes generated by GWHP systems and what is the potential of these organisms to grow under the environmental conditions generated by this shallow geothermal technology use? Finally, in the longer term, do these systems pose a threat to the urban aquifers' fate as a major source of urban water-supply worldwide (McDonald et al., 2014)? The insights identified in this study may be of interest to Water Authorities and City Managers concerned about their water reservoirs. To answer these questions, we examined a comprehensive set of 31 groundwater monitoring points at a city scale perspective. We analyzed statistically mean differences of pathogenic bacteria contents between impacted and non-impacted monitoring points, which allowed us to discover a significant and generalized decrease in waterborne pathogen contents in thermally impacted piezometers. This decrease, together with the finding that bacteria start to recover with increasing distance from the injection point allowed us to discuss the possible existence of a heat shock to bacteria within the heat exchangers. Finally, this work reinforces the concept of this renewable energy technology being a clean energy source by proving that it prevents the multiplication of preexisting pathogenic bacteria in groundwater bodies.

2. Materials and methods

2.1. Area of study

The study area is located in the central sector of the Ebro Basin (NE of Spain) comprising the metropolitan area of Zaragoza (Fig. 1). The climate in this sector corresponds to a Tropical and Subtropical Steppe Climate (Peel et al., 2007) with an average yearly temperature of 15 °C. On average, the warmest month is July (average temperature of 24.5 °C) and the coolest one is January (6.4 °C). The average yearly amount of precipitation in Zaragoza is 335.3 mm, with the highest precipitation occurring in May and the lowest in August. The city of Zaragoza is underlain by an Early Pleistocene fluvial, alluvial and Aeolian package of sediments configuring a shallow unconsolidated aquifer known as "The Ebro Alluvial Aquifer" (Fig. 1). This deposits consist of siliceous and carbonate grain-supported gravels occurring in tabular bodies with cross-bedding structures where intercalated sandy lenticular bodies can be found and clays dominate locally (Luzón et al., 2012). These detrital materials, in turn, are underlined by an Oligo-Miocene subhorizontal gypsum and interlayered marl and shale layer formation defined as "Zaragoza Gypsum Formation" (Quirantes, 1978; Salvany et al., 2007).

In general, groundwater flows towards the river Ebro, i.e., following a northeastern direction in the right margin and following a southeastern direction in the left margin. Transmissivities in the unconsolidated urban aquifer vary from $3 \cdot 10^2$ up to $4 \cdot 10^3$ m^2 day^{-1}. Since the early 2000s, the urban alluvial aquifer has experienced increased intensive geothermal exploitation, whereas 68% of the groundwater demand in the city corresponds to geothermal use (Garrido et al., 2012). A total of 65 GWHP systems are currently active in the urban area of Zaragoza