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Groundwater quality impacted by land use/land cover change in a semiarid region of Mexico

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ABSTRACT

Aquifers in arid and semi-arid areas face great challenges, one of which is implementing a sustainable management instead of mining nearby aquifers. A further challenge is relying on scant and fragmented groundwater information. This study related water quality to land use/land cover (LU/LC) to better understand the response of two aquifers in northern Mexico, Tabalaopa-Aldama (TAB) and Aldama-San Diego (ASD), to human stresses. Fifteen wells were sampled in May, July and October of 2015. The results show a water quality variations with respect to season and to areas where LU/LC has recently changed. Contaminants of concern are As, F, and nitrate. While As and F are natural contaminants, nitrate is anthropogenic, likely a result from wastewater and/or agricultural waste discharges. A relationship between water quality and LU/LC change was observed. Each basin suffered about 46 km^2 loss in rangeland between 1993 and 2012; TAB basin to urban and ASD basin to agricultural use. Besides exposing the location of contamination and type of contaminants, water quality data can be used to assess the rate at which aquifers are being degraded (or reclaimed), whereas the combination water quality - LU/LC change offers insights on potential practices that could be implemented towards sustainability.

1. Introduction

Long-term sustainability has been identified as a priority for groundwater management in arid areas on a global scale (Neri-Ramirez et al., 2013; Gorelick and Zheng, 2015). Arid and semi-arid areas around the world (e.g., Southwest USA, Middle East, northwest China, northern Mexico) face the great challenge of satisfying the water needs demanded by urban, industrial and agricultural uses (Zhang et al., 2014; Robertson and Sharp, 2015; Shalev et al., 2015), a task especially hard in locations where, in addition to these stresses, the population is expanding (Gorelick and Zheng, 2015). The city of Chihuahua in northern Mexico is a prime example of the latter as population has increased from about 600,000 in 2000 to 900,000 in 2015, and is projected to surpass one million in 2030 (CONAPO, 2016). To supply the city's drinking water needs, water is extracted from 153 wells spread over three contiguous aquifers (Chihuahua-Sacramento, El Sauz-Encinillas, and Tabalaopa-Aldama), plus surface water collected by three small dams. Two of these aquifers are severely overexploited, while the Tabalapopa-Aldama (TAB) is at the limit of exploitation.

In 1985, after the local aquifers and surface water were insufficient to supply the water demanded by the city, water from the El Sauz-Encinillas aquifer, 35 km north of the city of Chihuahua, was diverted to supply the needed water. Since this diversion, the Sauz-Encinillas aquifer developed a water deficit and Lake Encinillas dried up (CONAGUA, 2015a). Without a sustainable plan in place for managing these aquifers, it is foreseeable that the city will look at other nearby aquifers as potential water suppliers, e.g. Aldama-San Diego (ASD) and Laguna de Hormigas (LH) aquifers (IMPLAN, 2009). Fig. 1 shows the location of the two aquifers under study, the Rio Chuvíscar that crosses them, and the names of the surrounding aquifers. Table 1 lists major characteristics of the TAB and ASD aquifers, as well as those of two nearby aquifers for comparison purposes.

Aware of the need to incorporate measures and policies towards water sustainability, actions have been proposed by city and state

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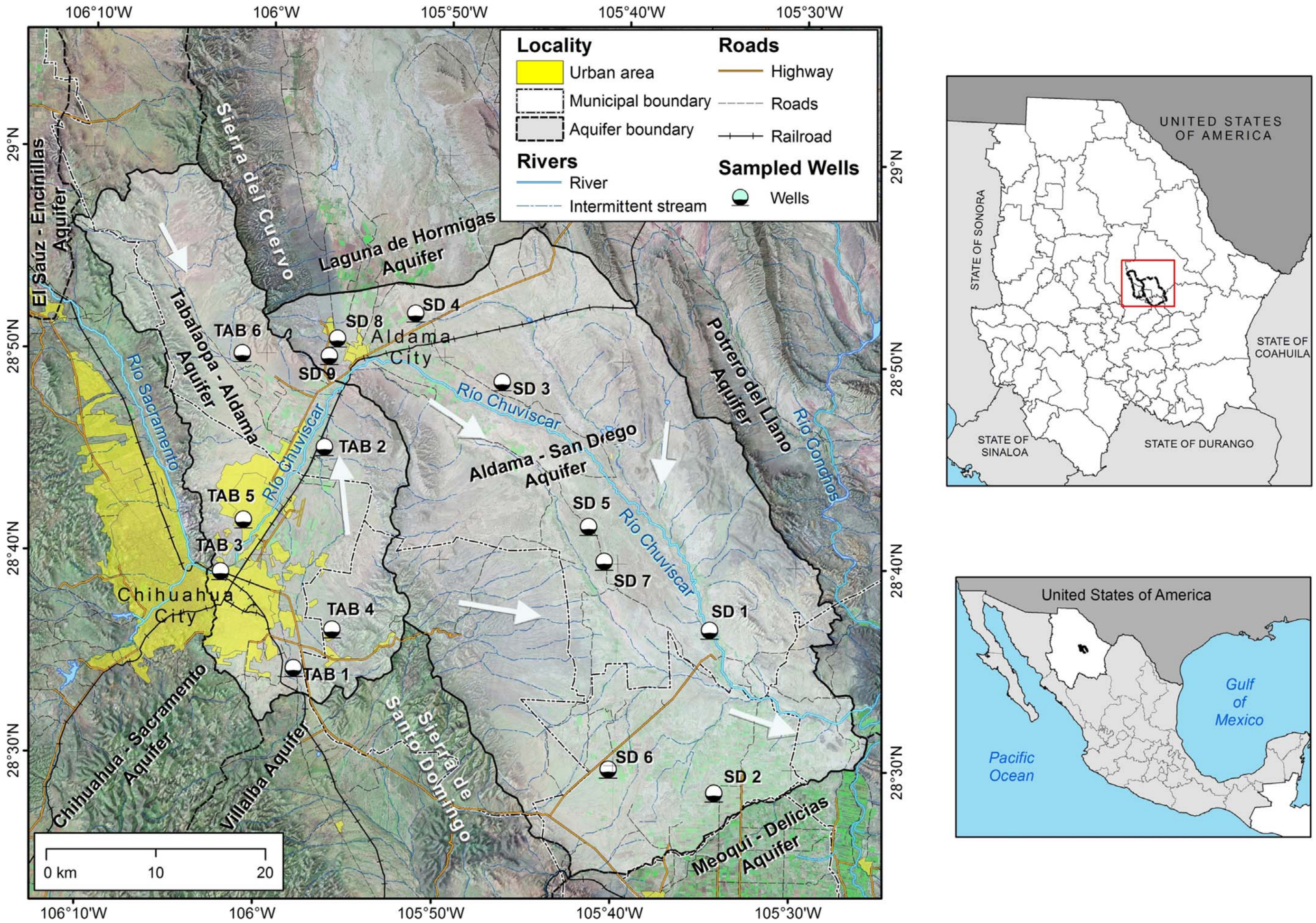

Fig. 1. Study area. Location of Tabalaopa-Aldama (TAB) and Aldama-San Diego (ASD) aquifers and sampled wells. White arrows show the direction of the regional groundwater flow.

agencies, requesting more stringent water conservation practices from citizens and the agricultural sector (IMPLAN, 2009). However, only a few of the proposed actions have been implemented in the past few years; among these, the outflows from the city's two secondary-treatment wastewater facilities (the first plant started operations in 2000 and the second plant in 2005) were used to irrigate public parks before being discharged into the Rio Chuvíscar. Several water conservation awareness programs were also launched. In spite of these, the water savings have not kept up with the increase in water demand, as indicated by the further dropping of aquifer water levels in 2014 (CONAGUA, 2015a, 2015b, 2015c) and confirmed presence of anthropogenic contaminants in groundwater asserted as increases of Cl^-, NO_3^- and SO_4^{-2} in groundwater and a positive relation between them and δO^{18} (Mahlknecht et al., 2008).

The effect of Land Use/Land Cover (LU/LC) change on groundwater depletion/recharge in arid and semi-arid regions has been addressed by several investigators, including Scanlon et al. (2005), Zhang et al. (2014), and Robertson and Sharp (2015). Common LU/LC changes in arid areas include rangeland to agricultural and rangeland to urban. Changing rangeland to agricultural use in semi-arid areas produce a downward displacement of nutrients, otherwise negligible in rangeland (Scanlon et al., 2005; Robertson and Sharp, 2015). Recharge also varies with dry *vs.* wet agriculture and conventional vs. efficient irrigation (Scanlon et al., 2005). Impacts of LU/LC change from rangeland (non-agricultural) to urban have also been reported as a decrease in percolation and an increase of runoff depending on the degree of urbanization (Hamadi et al., 2012).

Hydrological modeling has been conducted exhaustively with

Table 1
Aquifers physical characteristics. Values in 10^6 m^3/year except when noted (CONAGUA, 2015b, 2015c).

Aquifer	Tabalaopa-Aldama (TAB)	Aldama-San Diego (ASD)	Chihuahua-Sacramento	Meoqui-Delicias
Surface area, km^2	728	1620	1889	4830
Average thickness, m	1200	400, thins to the north	350	500
Depth of wells, m	100–250	100–200	25–300	100–425
Recharge (year)	76.5 (2007)	62.5 (2007)	55 (1999)	418 (1999)
	76.5 (2014)	62.5 (2014)	57 (2014)	418 (2014)
Withdrawals (year)	58.0 (2007)	63.6 (2007)	125 (1999)	211 (1999)
	59.8 (2014)	41.6 (2014)	102 (2014)	383 (2014)
Water balance (year)	18.5 (2007)	− 0.9 (2007)	− 56 (1999)	0 (1999)
	16.7 (2014)	22.0 (2014)	− 45 (2014)	− 172 (2014)
% volume for agriculture	52.3	88.7		
Main use	Urban	Rangeland	Urban	Agriculture