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Spatial distribution of nitrate health risk associated with groundwater use as drinking water in Merida, Mexico

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ABSTRACT

Water containing nitrate levels above 45 mg/l is not recommended for human consumption and its prolonged intake is associated with various health conditions. In Merida city, Mexico, the only source for water supply is a karstic aquifer, but the absence of sewerage and drainage networks makes it highly vulnerable to anthropogenic contamination. In this work, the concentration and spatial distribution of nitrate in the Merida's karstic aquifer were assessed by statistical and geostatistical techniques. The sources of nitrate contamination were tracked by making statistical correlations between nitrate concentrations and key ions; the potential risk to human health was also estimated by using the Hazard Index (HI). A total of 177 groundwater samples were collected from the four water supply systems serving Merida, during 2012 and 2013. Nitrate concentrations from collected samples varied between 15.51 and 70.61 mg/l, with maximum and minimum concentrations per sampling point ranging from 47.47 to 70.61 mg/l and from 15.51 to 17.32 mg/l, respectively. Significant positive correlations ($P < 0.05$) between nitrates and chlorides, sulphates and potassium were found, which may indicate potential contamination from domestic wastewater and agricultural activities. The spatial distribution of nitrate concentrations in the aquifer revealed an increase in nitrates following a trajectory South–North West, towards central and northwestern zones within Merida Metropolitan Area. From the health risk analysis, it was found that infants exposed at current nitrate levels are at a higher risk ($HI_{MAX} = 1.40$) than adults ($HR < 1.0$) and therefore, there is a clear need for implementing effective strategies to protect groundwater quality and to better manage and control nitrate pollution sources.

1. Introduction

In different regions around the world, environmental or quality-related water shortage is associated to poor water quality caused mainly by rapid economic development and urbanization, which in return affects the possibility to achieve sustainable socio-economic development, particularly in emerging economies and developing countries. In Latin America for instance, 70% of the water supplied to urban settlements returns to the environment without treatment, which affects not only the quality of water in rivers and coastal areas, but also increases public health risks to the resident population (mainly to the poor) and causes billions to be lost in economic activities including tourism and real state revenue (World Bank, 2012). Therefore, there is a clear need for developing science-based strategies integrating the water cycle with sustainable socio-economic development for integrated water resource management and governance.

Mexico has a current population of about 125 million people and it has been predicted that by 2030, communities residing in 12 out of their 13 hydrological-administrative regions (HARs) will be affected by water shortage. (Semarnat and INE, 2006). The Yucatan HAR, comprising the Mexican states of Campeche, Quintana Roo and Yucatan, has a higher availability of water resources (7603 m^3/person/yr) when compared with the national

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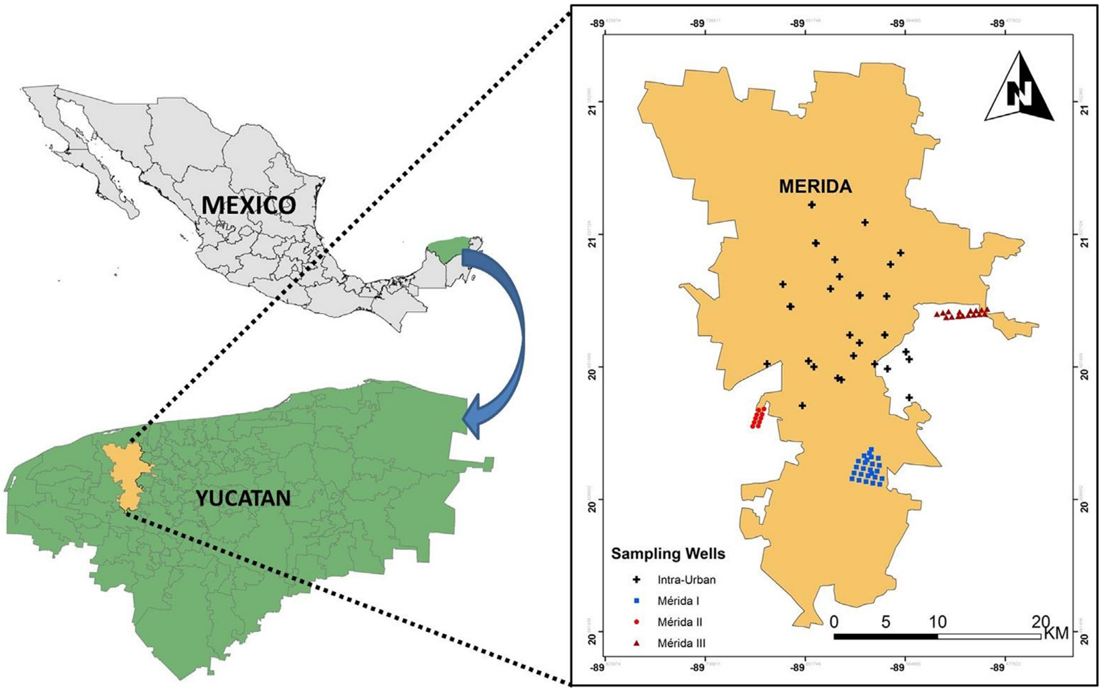

Fig. 1. Map of the study area and location of drinking water supply wells.

mean (4210 m^3/person/year) (Semarnat, 2008); however, their entire population (aprox. 3.1 million) mainly relies on groundwater as the sole source for water supply (i.e., domestic, industrial and agricultural uses). This aquifer is a coastal and karstic aquifer and hence, it is highly vulnerable to natural and anthropogenic contamination (Gonzalez-Herrera, Martinez-Santibañez, Pacheco-Avila, & Cabrera-Sansores, 2014).

In the City of Merida, the capital of the Mexican state of Yucatan, groundwater is extracted from deep wells using pumps installed at 20–30 m under the water table and conducted to the local water treatment works for disinfection with chlorine gas, as the only treatment process before distribution to the consumers.

The City of Merida lacks of integrated sewarage and drainage networks and wastewater management is mainly provided *in-situ* or in decentralized wastewater treatment systems, but regardless the alternative, the final disposal is always via a direct or indirect discharge into the aquifer. Urban wastewaters are commonly disposed through privately-owned individual septic tanks followed by infiltration wells causing a scattered contamination of the shallower groundwaters (Graniel, Morris, & Carrillo-Rivera, 1999); some neighborhoods with large, community septic tanks have added small sewage treatment units to polish the quality of their effluent before discharge into the aquifer (i.e., activated sludge with nitrification and disinfection). There are very few wastewater treatment systems in Merida (i.e., 24 at the most) serving new housing developments mainly located outside the outer ring road of the city, but the majority of them are currently underload and do not make a significant difference considering the fact that there are more than100 neighborhoods and enclosed urban developments (Seduma, 2010; PIDEM, 2012).

Nitrate is an important parameter in assessing groundwater pollution from diffuse sources and has been used as a surrogate indicator to determine groundwater vulnerability to contamination (Evans & Maidment, 1995). Nitrates are used in the formulation of industrial fertilizers and can also derive from the oxidation of ammonium and other nitrogen compounds found in wastewaters. They have adverse effects on human health, mainly causing methaemoglobinaemia in infants but also in pregnant women and the elderly (Sajil, Jegathambal, & James, 2014) and hence, their concentration is limited in drinking water. Besides methaemoglobinaemia, it has been mentioned that the consumption of water contaminated with nitrate may cause gastric cancer, multiple sclerosis, Non-Hodgkin lymphoma and thyroid gland hypertrophy, among other health conditions (Suthar et al., 2009). The World Health Organization (WHO) has set a guideline value for nitrate in drinking water of 50 mg/l as nitrate ion, which is based on epidemiological evidence for methaemoglobinaemia in infants resulting from short-term exposure and aiming

Table 1
Characteristics of the water supply system serving the city of Merida.

Water treatment works	Location	Area (Ha)	Number of wells, flow rate (l/s)	Serving area in Merida
Merida I	Southeast Merida, Cuxtal Reserve	625	24 wells, 1200 l/s	Center and South
Merida II	Southwest Merida	72	10 wells, 500 l/s	South and West
Merida III	East Merida	316	4 out of 17 wells, 700 l/s.	North and East
Backup water supply well system (intra-urban wells)	Distributed in the central part of Merida	-.-	37, Variable flow rate	Center
Independent water supply systems	Recent housing developments (outside of city's outer ring road)	-.-	112, Variable flow rate	Outside of the city's outer ring road

Source: Modified from PIDEM (2012).