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Arsenic contamination associated to hydrologic confinement a case study report

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RESUMEN

La intoxicación por arsénico puede causar cáncer, diabetes, enfermedades del corazón e incluso la muerte. Este es un reporte de la asociación estadísticamente significativa encontrada entre confinamiento hidrológico y la ocurrencia de arsénico en agua subterránea, en la región fronteriza entre El Paso Texas y Cd. Juárez, Chihuahua, donde las más altas concentraciones de arsénico disuelto (hasta 95 ppb) fueron observadas en acuíferos confinados. En diversos estudios se ha observado que el confinamiento hidrológico puede ser un factor en la contaminación por arsénico. En este trabajo se usaron técnicas estadísticas en una base de datos del gobierno de USA, que incluye contenido químico del agua y la zona hidrológica de cada pozo muestreado. Después de aplicar tests matemáticos-estadísticos, se encontraron sendas asociaciones significantes entre concentraciones de arsénico y pH, con el confinamiento hidrológico ($R=0.526$, p-value<0.001; $R=0.546$, p-value<0.001), T-test de diferencia de medias de arsénico apoya dicha diferencia entre confinamiento y no confinamiento.

ABSTRACT

The arsenic intoxication may lead to cancer, diabetes, heart disease, and sometimes to death. This is a case study reporting the statistical association found between arsenic in groundwater and confinement of the aquifers. The study region is the basin underlying the borderline between El Paso, Texas and Ciudad Juarez, Chihuahua, where the highest arsenic concentrations (up to 95 ppb) were observed in confined units. Here statistical techniques were applied to governmental groundwater databases from the USA, which include dissolved arsenic and the hydrologic zones of the sampled wells. The associations of arsenic and pH concentrations, both with the hydrological confinement were significant ($R=0.526$, p-value<0.001; $R=0.546$, p-value<0.01). T-test of difference of means supported the significance of the arsenic difference between wells confined and not (p-value<0.001).

Introduction

This work reports the statistical association found between arsenic concentrations in groundwater, and the confinement of the aquifers under the borderline between El Paso, Texas, USA, and Cd. Juarez, Chihuahua, Mexico. The geographical coordinates of El Paso City are: 31.8° North, 106.4° West, and elevation of 3943 ft.

Arsenic contamination of water has been a world wild health concern since the 1980's when arsenic concentrations in aquifers of Bangladesh registered the largest concentration measured to that date in groundwater. Arsenic intoxication may cause arsenicosis, lung, kidney, skin cancers, or other serious diseases. As the year 2016 dissolved arsenic rule for MCL is 10 ppb in the USA (EPA, 2001; Smedley and Kinniburgh, 2002; Stollenwerk et al., 2007).

Investigations in geochemical mobilization processes are profusely studied since 1980's, including mostly geochemical cycles and also hydrologic factors (Cavalcanti, 2007; Radloff etal., 2011; Stollenwerk et al., 2007; Smedley and Kinniburgh, 2002). This work focuses in the less profusely studied hydrologic factors particularly the confinement of the aquifers.

Bangladesh, that extends on 57,000 square miles, has an arsenic pollution in drinking water reaching concentrations up to 300 ppb (Smith et.al, 2000), although also reported up to 800 ppb (Frisbie et.al, 1998). In the region studied here, namely El Paso region, extended on approximately 350 square miles, the average arsenic concentration is about 8.2 ppb. The arsenic in El Paso affects to 46 wells currently yielding excessive amounts of arsenic (>10ppb), which caused El Paso Water Utilities construction of a 60 million gallons per day (mgd) arsenic removal facility (Bitter, 2006).

Works considering confinement were revised. In 2007 Cavalcanti, found conclusions similar to this work's in confined aquifers formed within glaciomarine sediments in the border states of Washington, USA, and British Columbia, Canada. In 2005 Erickson and Barnes found association of arsenic in upper confined units in glacial till, in Minnesota. These works found associations of arsenic with confinement, but they didn't test the means difference of the associations. Previous work in the El Paso, Juarez region (Marquez et.al, 2011) found interesting associations among arsenic, competitive ions, pH, here we try to augment the investigation with the hydrologic factor.

Metodology

Statistical techniques are among the most productive ones to investigate large black-box systems, since they rely in a sample of observations rather than upon often costly experiments (studying 350 square miles may cost large amounts of money).

Here were calculated Pearson's and Spearman's bivariate correlations between arsenic and confinement, pH and confinement; performed the Levine test of equality of variances, and the t-test for equality of means of arsenic between confined and not. Statistical analyses and graphs were made with SPSS v 16.0, 2007. SPSS Inc. Chicago, IL 60606-6412, USA.

Database and Units. A complete data base from El Paso Water Utilities EPWU was used, with about 837 individual observations of trace arsenic. Arsenic concentration units, as a trace element, are in parts per billion, ppb, or micrograms per liter µg/l. The mean of observations per well was analyzed as a data point. Therefore the means reported bellow are means of the means per well.

Results and Discussion

The arsenic statistics of all the wel means, descrive the mean (of means per well) as 8.50 ppb, median 7.4 ppb, minimum 1.0 ppb, maximum 27.67 ppb, std. deviation 4.5 ppb, N 174. The statistics of the individual values (not averaged per well) are: mean arsenic 9.64, minimum 0.8, maximum 95, std. dev 6.41, N 837. The bivariate Pearson's correlation coefficient between arsenic mean of means and confinement regime in the hydrologic units was R=0.526, p-value<0.001, the Spearman's was R=0.516, p-value<0.001. See Table 1 for the means (of means per well) and standar deviations of arsenic concentrations for all wells.

Table 1. Arsenic concentrations of means per well, in ppb. in wells tapping confined or not confined (water table) units. (this work, 2016).

confined	N wells	Mean of means per well. As ppb	Std dev
Yes (1)	32	13.6	4.71
No (0)	156	7.31	3.39

The average concentration of mean arsenic per well, in groundwater in 32 confined wells was 13.3 ppb, see Table 1. From the entire sample of 188 wells, 57 observed concentrations larger or equal to 10ppb; 30 of them were in confined fields. Only four confined wells, observed no arsenic. The correlation of pH and confinement calculated is R=0.546, p-value<0.01.

To test the statistical significance of the difference of the mean concentrations, we performed a t-test for difference of means, which support with significance < 0.001 the hypothesis that arsenic in confined units is significantly higher than it is in water table units. See Table 2. Levine's test for equallity of variances showed F = 2.179 with sig. 0.142, implying we can consider equal variances between the two (confined, not confined).

Table 2. Arsenic per well, t-test for equality of means (of means per well) of arsenic between confined and not (water table) units. (this report, 2016).

	t	Sig. (2-tailed)	As Means Difference	95% Confidence Interval of the Difference	
				Lower	Upper
Equal variances assumed	8.887	.000	6.294	4.897	7.692
Equal variances not assumed	7.184	.000	6.294	4.520	8.068

The test for equality of means assesses the exceptionality of a difference between two groups, in this case one group formed by the table wells and the other group formed by wells taping confined units. Table 2 shows that the statiscs "t" for the difference has a value of 8.887 (rather than zero), with a very small p-value<0.001, which may interpret that it is oddly rare to find that difference when both groups belong to the same population, if that population is approximatelly normally distributed.

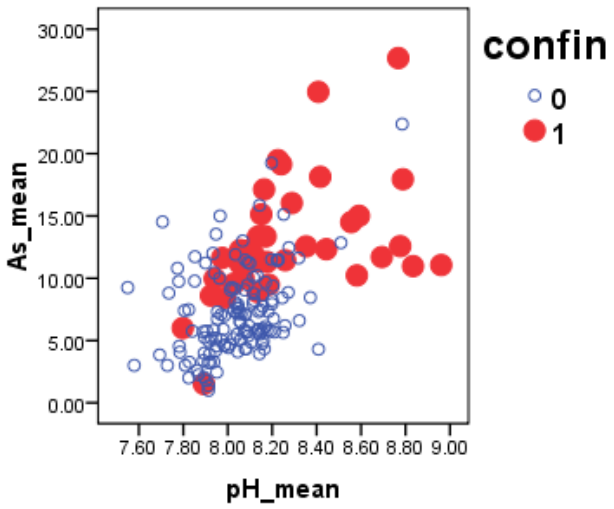

Figure 1. Scatter plot of 286 wells. Arsenic vs. pH mean values per well. Filled red dots are from confined aquifers, small circles from water table wells. (this report, 2016).

Conclusions

This work targeted the hydrologic confinement as a factor associated to arsenic in groundwater, rather than geochemical processes, trying to give a new piece of information to the puzzle that help to explain the likely causes of high arsenic concentrations; for example answering why in the El Paso region many adjacent wells (in the order of 10 miles apart), have yield two very different arsenic concentrations in water (e.g. 1ppb vs. 20ppb).

The correlation between arsenic, pH, and confinement of aquifers are significant, p-value<0.001, and tests for difference of concentration of means, between confined and not confined aquifers support the significance of the difference; in other hand other works studied arsenic mobilization (desorption and reductive disolution), associated to pH values (Cavalcanti, 2007; Erickson and Barnes, 2005; Marquez et al., 2011; Stollenwerk etal., 2007). Hence in this study region, the confined units, where hydrologic quasi-insulation persists, may facilitate competitive desorption and disolution of arsenic into the groundwater.

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