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The temporal stability of arsenic concentrations in well water in western Nevada ☆

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Abstract

Millions of people worldwide are exposed to drinking water containing arsenic, and epidemiologic studies have identified associations between the ingestion of arsenic-contaminated water and increased risks of cancer. In many of these studies, the assessment of arsenic exposure is based on a limited number of drinking water measurements, and the assessment of long-term or past exposure relies on the assumption that arsenic concentrations in sources of drinking water remain stable over time. In this investigation, the temporal stability of arsenic concentration was assessed in 759 wells in western Nevada state in the USA. Arsenic concentrations in these wells ranged from nondetectable to 6200 μg/L (median, 10 μg/L; standard deviation, 335 μg/L). Spearman correlation coefficients between arsenic concentrations measured in the same wells over a period of 1–5, 6–10, and 11–20 years apart were, respectively, 0.84 [95% confidence interval (CI), 0.81–0.86), 0.85 (95% CI, 0.81–0.88), and 0.94 (95% CI, 0.88–0.96). These findings suggest that, in this study area, arsenic concentrations in most wells remain stable over time and a limited number of measurements per well can be used to predict arsenic exposures over a period of many years.

Keywords: Arsenic; Cancer; Drinking water; Environment; Epidemiology

1. Introduction

Inorganic arsenic occurs naturally in the groundwater of many parts of the world, and millions of people worldwide are exposed to drinking water containing this known carcinogen (Cebrian et al., 1983; Chen et al., 1988; Chowdhury et al., 2000; Focazio et al., 2000; Hopenhayn-Rich et al., 1996; Khan et al., 1997; Kurttio et al., 1999; Luo et al., 1997; Smith et al., 1998). Most of the data used to characterize the associations between ingested arsenic and cancer have come from epidemiologic studies in which assessments of exposure are based on measurements of the arsenic concentration in the drinking water sources used by each study subject (NRC, 2001). In many instances, however, only a single or a few arsenic measurements are collected from each drinking water source, even for those sources used by study subjects for many years. In some studies, recent measurements of arsenic concentration are used to predict exposures from several decades in the past (Bates et al., 2004; Steinmaus et al., 2003). Since the latency of arsenic-caused cancer may be 20 years or more (NRC, 2001), the ability of these studies to accurately predict true exposure relies on the assumption that arsenic concentrations in drinking water sources remain fairly stable over long periods of time. To date, however, few studies have assessed the validity of this assumption.

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In this article, we report on the temporal stability of the arsenic concentration in 759 wells covering a period of up to 20 years. To our knowledge, this is the largest published study of this type. The measurements we use are from wells in six counties in western Nevada, an area that includes the largest population in the US with exposure to arsenic in drinking water.

2. Materials and methods

The study area includes the predominantly rural counties of Douglas, Churchill, Storey, Mineral, Lyon, and Carson City. The primary source of drinking water in this area is groundwater. Approximately 60% of the population obtain their residential drinking water from public wells while most of the remaining obtain their water from private domestic wells (Steinmaus et al., 2003). The arsenic concentrations range from nondetectable to 120 μg/L in public wells and nondetectable to over 6000 μg/L in private domestic wells.

The arsenic water measurements used in this investigation were obtained from records archived by the Nevada State Health Division. These measurements were performed by the state for a variety of reasons, including compliance with federal and local drinking water regulations and personal requests from private homeowners for reasons such as home sales or health concerns. For this investigation, we collected records from all wells with two or more arsenic measurements taken at least 1 year apart. These records were available on a standard form that included arsenic concentration, date, and the location the sample was taken. All arsenic analyses had been performed using hydride-generation atomic-absorption spectroscopy (Crecelius, 1978). Other details of analysis or sample collection were not included in these records. Public wells within the study area are identified by a Public Water Supplies Identification number. However, private wells do not have these unique identifying numbers and are identified in the state records by address (house number, street name, city, and zip code). Records for which a specific address was not provided were excluded. In approximately 60% of samples, the well depth was recorded. In some instances, different well depths were recorded for samples taken from the same address. Since these were thought to represent different wells at the same address, these records were also excluded.

The temporal variability in arsenic concentrations was assessed using Spearman correlation coefficients. Correlation coefficients were calculated for arsenic measurements taken from the same wells 1–5, 6–10, and 11–20 years apart. No records were available on wells with arsenic measurements more than 20 years apart. For some wells, more than two measurements were available. If the later measurements fell within the same time period (for example, two measurements within 1–5 years of the first measurement), these later measurements were averaged. Using the earliest measurement in any particular time period instead of this average had no impact on our results. If the later measurements were in different time periods, each result was used in the analysis of its respective time period. Detection limits varied from year to year and were recorded whenever the arsenic concentration was below the detection limit. Records with detection limits greater than 5 μg/L were excluded. For arsenic concentrations below the detection limit, levels were set at one-half the detection limit. All data analyses were carried out using the SAS statistical program package (Version 8.0e, SAS Institute, Cary, NC, USA).

3. Results

In total, 759 wells were included in this analysis. Arsenic concentrations ranged from nondetectable to 6200 μg/L. The mean and median arsenic concentrations were 92 [standard deviation (SD), 335 μg/L] and 10 μg/L, respectively. The number of wells with arsenic concentrations at <5, 5–10, 11–50, 51–200, and >200 μg/L was 268 (35%), 170 (22%), 152 (20%), 93 (12%), and 76 (10%), respectively. Information on well depth was available for 463 wells (61%). The mean and median well depths were 28 (SD, 46 m) and 16 m, respectively. Seven hundred twenty-nine (96%) of the wells used in this study were private domestic wells, while the remaining were public drinking water wells.

The Spearman correlation coefficients between arsenic concentrations measured in the same wells 1–5, 6–10, and 11–20 years apart were 0.84 [95% confidence interval (CI), 0.81–0.86], 0.85 (95% CI, 0.81–0.88), and 0.94 (95% CI, 0.88–0.96), respectively (Table 1). A large proportion of the wells used in this investigation had relatively low arsenic concentrations. In order to assess the impact of this on our results, we performed a separate analysis confined to wells with arsenic

Table 1
Spearman correlation coefficients between arsenic concentrations measured in the same wells over time

Years apart	N[a]	R	95% CI
1–5	557	0.84	0.81–0.86
5–10	228	0.85	0.81–0.88
11–20	44	0.94	0.88–0.96

N, number of wells; R, Spearman correlation coefficients; CI, confidence interval.

[a]The sum of the wells from each time period exceeds the total number of wells since some wells had results for more than one time period.

concentrations of 5 μg/L or higher. In this analysis, Spearman correlation coefficients taken 1–5, 6–10, and 11–20 years apart were 0.71 ($n = 394$ wells), 0.76 ($n = 170$ wells), and 0.91 ($n = 26$ wells).

Fig. 1 displays the arsenic measurements used in this investigation. For most wells, little difference is seen in the measurements taken from the same wells at different points in time. However, in a few wells, large temporal changes are seen. For example, in the analysis of samples taken 5–10 years apart, six wells (3%) have one recorded measurement below 10 μg/L and one recorded measurement above 50 μg/L.

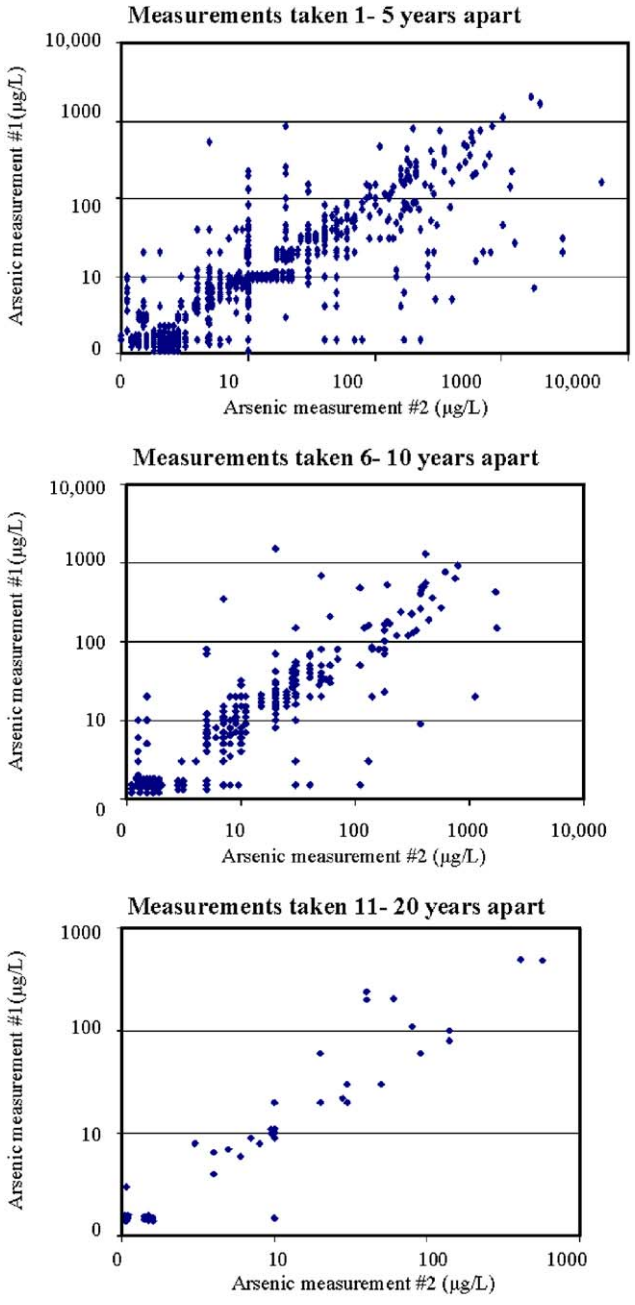

Fig. 1. Temporal variability in arsenic concentrations in wells in western Nevada.

4. Discussion

The correlation coefficients reported here indicate that, in most drinking water sources in our study area, arsenic concentrations remain stable over time and, for these sources, a single assessment of arsenic concentration can be used to accurately predict arsenic exposure over a period of many years. Although large changes in arsenic concentration were seen in some wells, these represented only a small portion of the total number of wells evaluated in this investigation.

It is unknown whether the results of this investigation can be extrapolated to other areas in the USA. Only a few other investigations on the temporal stability of arsenic in US well water have been published. In one of the larger studies, the United States Geological Survey (USGS) investigated the temporal stability in all wells in the USGS National Water Information System database that contained 10 or more arsenic measurements (Focazio et al., 2000). Temporal trends in 355 wells were examined by performing a regression of arsenic concentration on time for each well. Regression coefficients varied from 0 to 0.8, although most were below 0.3, indicating that little unidirectional change was seen in the arsenic concentration of most wells. In approximately 5% of wells, regression coefficients were above 0.5, although the magnitude of these changes and the time period over which they occurred are not given. In a separate study, arsenic concentrations were measured 3–5 years apart in the tap water of 99 subjects in the state of New Hampshire (Karagas et al., 2001). The intraclass correlation coefficient between measurements taken from the same tap water supplies was 0.85 (95% CI, 0.79–0.89). In a study in the state of Maryland, six arsenic measurements were collected at 2-month intervals from the primary water supplies of 73 subjects (Ryan et al., 2000). The mean correlation coefficient among pairs of sampling cycles was 0.90 (P value not given). Arsenic concentrations were very low in this area (upper 95th percentile, 2.58 μg/L), so the relevance of this study with regard to arsenic levels at or above the US standard of 10 μg/L are unknown. In a study done in Churchill County, which is part of our study area, little change was seen in the arsenic concentration in 29 wells from 1989 to 2001. The Wilcoxon signed-rank test P value for the difference in measurements over time was greater than 0.05, although the exact P value was not reported (Seiler, 2004).

Several other studies involving smaller numbers of wells have reported large changes in arsenic concentrations over time in some wells (Cebrian et al., 1983; Frost et al., 1993; Nadakavukaren et al., 1984). For example,

in an analysis of repeated arsenic measurements collected from 14 wells in Lane County in the state of Oregon over a 13-month period, arsenic concentrations remained relatively stable in the 7 wells that had average arsenic concentrations below 50 μg/L (Nadakavukaren et al., 1984). However, in the 7 wells with higher average concentrations, large seasonal changes were seen. In one well, arsenic concentrations were over 1000 μg/L in the summer months and less than 50 μg/L in the winter months. The reasons for these changes are not known. However, this area receives much more rainfall than our study area (NWS, 2004), and the authors speculated that seasonal changes in rainfall or pumping rates may have affected the arsenic concentrations in these wells.

Overall, the results of our investigation and the findings of other studies suggest that arsenic concentrations in most wells in the USA remain fairly stable over time. However, these data also suggest that in some wells, large changes in recorded levels may be seen. The reasons for these changes are mostly unknown but could be due to seasonal variability, changes or errors in collection or analytical procedures, changes in water filter use or pumping rates, or other factors. In our study, we included mostly private domestic wells that were identified only by a household address. It is possible that in some instances two or more wells existed at the same address. Thus, for some addresses, we may have been comparing arsenic measurements from different wells tapping different aquifers. While we tried to reduce this possibility by eliminating those addresses with conflicting information on well depth, this information was only documented in 61% of the records used in our study. It is important to note, however, that this potential problem would most likely have biased our correlation coefficients toward zero, not toward the strong correlations we identified. Similarly, changes over time in pumping rates, filter use, sample collection procedures, season of collection, or analytical methods would also have biased our correlation coefficients toward zero. If these biases played a role in this study, true correlations may be even higher than those we have reported.

In summary, we found a strong correlation between arsenic measurements taken from the same wells over a period of 1–20 years. Correlation coefficients remained high as the time between well sampling increased. This suggests that strong a correlation may continue beyond the 20-year period covered by this study. Some of the health effects associated with arsenic appear to have induction periods of 20 years or more (NRC, 2001). Most epidemiologic studies of arsenic and chronic health effects classify subjects into broad categories of past arsenic exposure. Our results suggest that, at least in our study area, a single or a few arsenic measurements can be used to predict the arsenic concentration in a particular well over a period of many years and can be used to accurately categorize subjects into broad categories of arsenic exposure. Further work is needed to explain why large changes in arsenic concentration were seen in some wells and help to establish whether the temporal stability we identified in our study also exists in other arsenic-exposed areas.

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