Available online at www.sciencedirect.com
ScienceDirect
Environmental Research 104 (2007) 367–373
Environmental Research
www.elsevier.com/locate/envres

Seasonal variation of arsenic concentration in wells in Nevada ☆

Josef G. Thundiyil[a,d,*], Yan Yuan[b], Allan H. Smith[b], Craig Steinmaus[b,c]

[a]Division of Occupational/Environmental Medicine, Division of Medical Toxicology, University of California, San Francisco, USA
[b]Arsenic Health Effects Research Group, School of Public Health, University of California, Berkeley, USA
[c]Office of Environmental Health Hazards Assessment, California Environmental Protection Agency, USA
[d]Orlando Regional Medical Center, Department of Emergency Medicine, 86 W. Underwood, Suite 200, Orlando, FL 32806, USA

Received 13 June 2006; received in revised form 22 February 2007; accepted 28 February 2007
Available online 24 April 2007

Abstract

The issue of seasonal arsenic measurement variability poses consequences regarding the interpretation and frequency of well water measurements for both public health research and surveillance. In this study, we evaluated seasonal variability in arsenic concentration in 356 wells in western Nevada. River flow data obtained from US Geological Survey National Water Information System were used to classify seasons as wet or dry, and mean differences in arsenic well concentrations measured during these seasons were compared. Arsenic concentrations in these wells averaged 72.9 μg/L (range, non-detect to 3000 μg/L). The mean difference in arsenic concentrations between the wet and dry seasons was −3.3 μg/L ($p = 0.78$; average percent difference = 2.3%). Eighty wells (22%) had higher arsenic concentrations in the wet season, 75 wells (21%) had higher arsenic concentrations in the dry season and no difference was seen in 201 wells (56%). The mean differences in wells with arsenic levels of 0–10, 11–50, 51–200, >200 μg/L were −1.4 μg/L ($p = 0.43$), 9.2 μg/L ($p = 0.36$), 15.1 μg/L ($p = 0.30$), and −49.9 μg/L ($p = 0.59$). In summary, although changes in arsenic concentrations were seen in some wells, clear trends in arsenic concentration over time were not associated with the wet and dry seasons. These findings provide evidence that, in our study area as a whole, little seasonal variability occurs in arsenic concentrations, and repeated assessments of arsenic concentrations based on season might add little value to the accuracy of health effects research or public health surveillance.

Keywords: Arsenic; Well water; Seasonal variability; River flow; Nevada

1. Introduction

Inorganic arsenic is a naturally occurring element present in the soil and groundwater in many regions of the world. Millions of people are exposed to arsenic in their drinking water especially from wells (Nordstrom, 2002; Focazio et al., 2000; Chowdhury et al., 2000). The associations between arsenic and human health effects, including lung cancer, bladder cancer, and other diseases, are well described (NRC, 1999, 2001). The new US standard for arsenic in drinking water which became effective on January 23, 2006 is 10 μg/L; however, this applies only to public water systems (USEPA, 2001). Importantly, 15% of the US population obtains their water from private wells which are not subject to this regulation (USGS, 2004; Ayotte et al., 2003; Welch et al., 1999; Steinmaus, C.M., et al., 2005). High arsenic concentrations have been documented in private wells in several states throughout the US (Frost et al., 1993; Kelly et al., 2005; Kim et al., 2002; Lewis et al., 1999; Nadakavukaren et al., 1984; Peters et al., 1999; Steinmaus et al., 2003; Steinmaus, C., et al., 2005).

Epidemiologic studies which have demonstrated associations between arsenic and cancer often rely on a single or few measurements to predict past exposure (Bates et al., 2004). Since the latency of many arsenic-induced cancers can be as long as 20 years or more, and because arsenic

☆ *Funding source*: Primary funding for this project comes from the National Institute of Environmental Health Sciences (NIEHS), Grant Numbers P42-ES04705 and R01ES7459. Additional support is provided by NIEHS Grant K23 ES11133 and the University of California, Center for Occupational and Environmental Health.

*Corresponding author. Orlando Regional Medical Center, Department of Emergency Medicine, 86 W. Underwood, Suite 200, Orlando, FL 32806, USA.
E-mail address: joseft@mindspring.com (J.G. Thundiyil).

0013-9351/$ - see front matter © 2007 Elsevier Inc. All rights reserved.
doi:10.1016/j.envres.2007.02.007

concentrations in any given well could change over time, it is not clear if one can rely on a single measurement to accurately estimate long-term arsenic exposure. This raises questions amongst investigators and public health personnel regarding how often and when to measure arsenic levels in wells.

Previous investigations in Nevada have demonstrated that arsenic concentrations remain stable over years (Steinmaus, C., et al., 2005; Seiler, 2004). However, several studies have shown that arsenic concentrations in some wells might vary dramatically by season, although these results have not been consistent across all studies (Savarimuthu et al., 2006; Nadakavukaren et al., 1984; Cheng et al., 2005; Rodriquez et al., 2004; Berg et al., 2001; Van Geen et al., 2002). Several mechanisms have been proposed by which rainfall or other seasonal changes may impact ground water arsenic concentrations including dilution by recharge of water with low arsenic concentrations, or seasonal changes in redox conditions, pumping rates, water movements, or water table depths (Tareq et al., 2003; Cheng et al., 2005; Nadakavukaren et al., 1984; Rodriquez et al., 2004). Areas in western Nevada have historically included one of the largest populations in the US exposed to high arsenic concentrations in drinking water (Focazio et al., 2000). In this inland arid environment, high arsenic concentrations in ground water are thought to be due to evaporative concentration of groundwater (enhanced by dry climate), high pH, and redox reactions which cause desorption of arsenic from metal oxides (Smedley and Kinniburgh, 2002). Whether the seasonal variability that has been seen in other studies also occurs in western Nevada is unknown. This area is markedly different from the other areas where seasonal variability has been assessed in that it has much lower direct precipitation levels (USGS, 2006; NCDC, 2006). Groundwater recharge in much of this area is thought to be due primarily to water from irrigation (Herrera et al., 2000) or from rivers flowing down from an adjacent mountain range via snowmelt runoff (Maurer and Berger, 2007), although some groundwater sources may contain water that is several decades or more old (Seiler et al., 2005). The goal of this paper is to evaluate whether the seasonal changes in arsenic concentrations that have been documented elsewhere also occur in dryer areas such as western Nevada.

This study, which examined 356 wells in western Nevada, is the largest investigation to date to study seasonal variability of arsenic levels.

2. Methods

The study area includes six counties in western Nevada: Douglas, Churchill, Storey, Mineral, Lyon, and Carson City. Approximately, 60% of the population in the study area obtains their drinking water from public wells and the remainder from private domestic wells (Steinmaus et al., 2003). This area receives relatively little rainfall and most of the regeneration of groundwater supplies may be from river flow or related irrigation (Maurer and Berger, 2007; Herrera et al., 2000). In this study, river flow data from the US Geological Survey Water Resources Data National Water Information System (2006) was used to define the wet and dry seasons. The Carson River, Walker River, and Truckee River are the predominant rivers in the study area. The Truckee River, however, only supplies approximately 5% of the study area. The historical river flow data for these rivers from 1982 to 2000, the period for which arsenic well water measurements were available for this study, at selected points within the six counties were obtained from publicly available data on the Water Resources Data National Water Information System (2006) website. These points were selected by the authors based on their proximity to population centers and the availability of complete data sets for the study period. The mean monthly river flow data dating back through the study period were calculated. Using this information, months were classified as wet, dry, or intermediate.

The arsenic measurements used in this study were obtained from archived records from the Nevada State Health Division. These records contained measurements taken between the years 1982 and 2000. Well measurements were prompted by owner request or if a well changed ownership. Laboratory analysis on all samples was done using hydride generation atomic absorption spectroscopy, however, many of the other specific methods and protocols for sample collection were not recorded. Wet and dry season arsenic concentrations were defined as not different if the values were within 5 μg/L or 5% of each other, whichever was greater. These values were chosen because they are about the precision and accuracy for arsenic measurements in water for hydride generation atomic absorption spectroscopy reported by the US Environmental Protection Agency (EPA) (Crecelius et al., 1986). Detection limits were listed on most but not all records and were variable from record to record. Almost all recorded detection limits ranged from 1 to 10 μg/L. Detection limits greater than 10 μg/L were listed on a few records and these were eliminated from our analysis. All records with at least one measurement in each of the two seasons (wet and dry) were included in this study. All other wells were excluded. Parts of the study area, specifically the western portions of Douglas County and Carson City are mountainous and are not arid like the remainder of the study area. Wells in these areas ($n = 20$ wells) were excluded. Some wells had more than one measurement taken in a given season. In these instances, the measurement taken first (i.e. that with the earliest measurement date) was used. For statistical purposes, measurements which were listed as being below the detection limit were classified as being one half the detection limit.

The seasonal variability in arsenic concentration was assessed using the paired *t*-test. The Wilcoxon sign rank test was also applied to evaluate the possible impact of extreme outliers. Analyses were performed for the entire data set as well as for specific categories of arsenic concentration in order to avoid the potential problem of having wells with very high arsenic levels overly influencing the results. The categories were: 0–10, 11–50, 51−200 μg/L, and greater than 200 μg/L. These levels were based primarily on the current and previous US EPA standards. In deep wells, where the water supply is older, groundwater recharge may be less impacted by riverflow (Seiler et al., 2005); henceforth, seasonal change for arsenic concentrations in wells in Nevada may be more pronounced for shallow wells. Consequently, for the wells with available information on well depth, Pearson and Spearman correlation coefficients were used to evaluate whether a relationship exists between well depth and seasonal change in arsenic concentrations.

A subset analysis for the entire study period was also conducted comparing only the three months with the highest river flow to the three months with the lowest river flow, also using the paired *t*-test and Wilcoxon sign rank test. A second subset analysis was conducted which included only the 11 years with the greatest divergence between wet and dry season river flow. In this analysis, there was an average river flow difference of four to five fold between wet and dry seasons. Both of these subset analyses were performed to enhance the differences in river flow between wet and dry seasons.

Research has suggested that in parts of our study area, applied irrigation may contribute substantially to groundwater recharge (Herrera et al., 2000). Using data on irrigation patterns in western Nevada from Herrera et al., the authors performed an additional analysis to evaluate

differences in arsenic concentrations based on irrigation patterns. This analysis was also done using the paired *t*-test and Wilcoxon sign rank test. In many wells, wet and dry season arsenic measurements were taken in different years (median = 3 years). In order to assess whether the time between measurements may have affected our analysis of seasonal variability, Spearman correlation coefficients were calculated for the relationship between the number of years between measurements and the difference in arsenic concentration across seasons. All data analyses were carried out using the SAS statistical program package version 8.0.

3. Results

River flow information from USGS National Water Information System database for the Carson, Walker, and Truckee Rivers is summarized in Fig. 1. River flow recordings varied from 6 to 3200 cubic feet/s. Based on relative river flow, months were classified as wet, dry, or intermediate: February through June was classified as wet, August through December was classified as dry, and January and July were classified as intermediate. February through June had an average river flow rate of 870 ft^3/s while from August through December it was 264 ft^3/s. This difference represents a three to four fold change in river flow between wet and dry seasons. This difference was most pronounced (five to six fold seasonal difference) for the Carson River, the main water supply for the region. In order to avoid exposure misclassification, arsenic measurements taken in January and July were excluded from the analysis due to intermediate and variable river flow and to account for a possible lag period between river flow and changes in arsenic concentration.

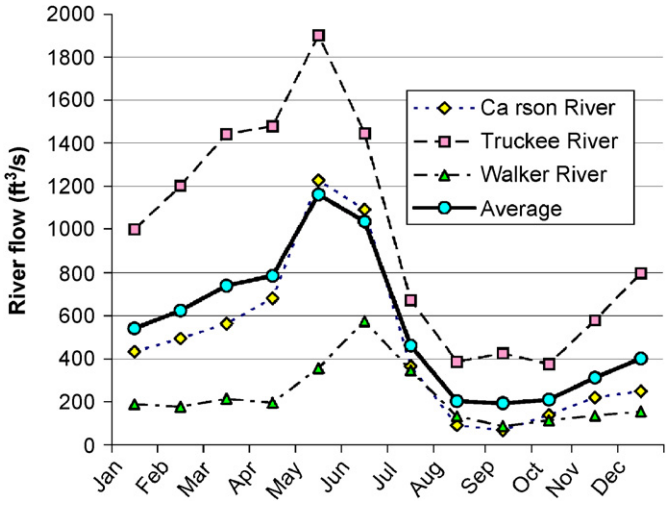

Fig. 1. Average monthly river flow (ft^3/s, western Nevada study area, 1982–2000).

We identified 356 wells, which had arsenic measurements taken in both the wet and dry seasons. The arsenic levels in these wells ranged from non-detectable to 3000 μg/L (average = 72.9 μg/L). The overall average difference between the wet and dry season arsenic measurements (wet minus dry) was −3.3 μg/L. These results are summarized in Table 1. Fig. 2 shows the comparison of all wet and dry season arsenic measurements in wells in a scatter plot. As demonstrated, although large changes are present in some wells, clear trends in these changes between wet and dry seasons are not seen. Table 2 shows the numbers and percentages of wells in which arsenic measurements were higher in the wet season, higher in the dry season, or showed no difference between seasons. Eighty wells (22%) had higher arsenic concentrations in the wet season, while 75 wells (21%) had higher arsenic concentrations in the dry season. No difference was seen across seasons in 201 wells (56%). No correlation was found between the number of years between measurements and the difference between wet and dry season arsenic concentrations ($R = 0.004$, $p = 0.93$).

In the analysis of wells by arsenic concentrations, the mean differences in wells with arsenic levels of 0–10, 11–50, 51–200, >200 μg/L were −1.4 μg/L ($p = 0.43$), 9.2 μg/L ($p = 0.36$), 15.1 μg/L ($p = 0.30$), and −49.9 μg/L ($p = 0.59$) (Table 1). For the first subset analysis, only the three months with peak runoff (April to June) were classified as wet months and the 3 months with lowest river flow (August–October) were classified as dry months. For the 159 wells which met this criteria, the average difference in arsenic concentration for the overall, 0–10, 11–50, 51–200, and >200 μg/L wells were: −14.1 μg/L ($p = 0.53$, median = 0.0 μg/L), −3.3 μg/L ($p = 0.46$, median = 0.0 μg/L), −2.5 μg/L ($p = 0.48$, median = 0.0 μg/L), 27.4 μg/L ($p = 0.30$, median = 0.0 μg/L), and −94.1 μg/L ($p = 0.47$, median = 20.0 μg/ L), respectively. For the subset analysis of the 11 years in which seasonal differences in river flow were the greatest, the average differences in arsenic concentration for the overall, 0–10, 11–50, 51–200, and >200 μg/L wells were:

Table 1
Mean differences between arsenic levels during wet and dry seasons

Arsenic concentrations (μg/L)	Number of wells	Mean seasonal difference[a]	*p*-Value (paired *t*-test)	*p*-Value (sign rank test)
0–10	193	−1.4	0.43	0.77
11–50	74	9.2	0.36	0.78
51–200	44	15.1	0.30	0.62
>200	45	−49.9	0.59	0.21
All wells	356	−3.3	0.78	0.48

[a]The seasonal difference in arsenic levels for each well was calculated by subtracting the arsenic level in the dry season from the arsenic level in the wet season. The mean seasonal difference is the average of the seasonal differences seen in each well. Wet season is defined as February through June and dry season is defined as August through December.

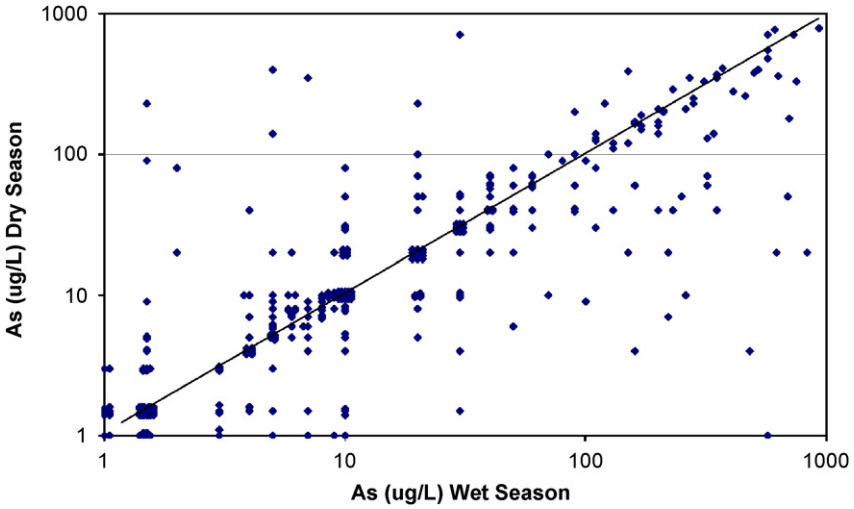

Fig. 2. Scatter plot of arsenic concentration in wells in dry and wet seasons. The line in the figure represents a 1:1 relationship.

Table 2
The number and percentage of wells in which the arsenic concentrations were lower, higher, or were no different[a] in the wet season compared to the dry season

Arsenic level	All		0–10 μg/L		11–50 μg/L		50–200 μg/L		>200 μg/L	
	N	%	*N*	%	*N*	%	*N*	%	*N*	%
Lower	75	21	11	6	26	35	22	50	16	36
Higher	80	22	16	8	21	28	19	43	24	53
No difference	201	56	166	86	27	36	3	7	5	11
Total	356	100	213	100	74	100	44	100	45	100

[a]Wet and dry season arsenic concentrations were defined as not different if the values were within 5 μg/L or 5% of each other, which ever was greater. These values were chosen because they are about the precision and accuracy for arsenic measurements in water for hydride generation atomic absorption spectroscopy reported by the US EPA (Crecelius et al., 1986).

−1.7 μg/L($p = 0.92$, median = 0.0 μg/L), −4.1 μg/L ($p = 0.41$, median = 0.0 μg/L), −1.7 μg/L ($p = 0.84$, median = 0.0 μg/L), 31.4 μg/L ($p = 0.31$, median = 0.0 μg/L), and −28.1 μg/L ($p = 0.81$, median = 40.0 μg/L), respectively.

Using applied irrigation as the predictor for wet and dry seasons, the wet season occurs during the growing season (April through August) and the driest periods occur from November to March (Herrera et al., 2000). There were 347 wells for which arsenic measurements during these two periods were available. Based on this classification, there was no significant change in mean arsenic concentration. The mean difference in arsenic concentration for all wells between periods of high and low irrigation was 3.0 μg/L ($p = 0.82$).

Information on well depth was available for 269 of the 356 wells used in this analysis. For these wells, we found no relationship between well depth and seasonal change in arsenic concentration (Pearson $R = 0.05$, $p = 0.40$).

4. Discussion

The issue of seasonal arsenic measurement variability poses consequences regarding the interpretation and frequency of well water measurements. Previous studies have demonstrated seasonal variability of arsenic levels when measured in surface streams (Cheng et al., 2005; Sanchez-Rodas et al., 2005; Gault et al., 2003; Olias et al., 2004; McLaren and Kim, 1995). Stream variability has been hypothesized to be related to deliberate pollution, water pH, and release of other metals which can adsorb arsenic (Olias et al., 2004; Maher and Butler, 1988; Gault et al., 2003). In the studies from Spain (Olias et al., 2004) and Washington state (Johnson, 2002), arsenic levels were found to be highest during periods of high streamflow. On the contrary, in France, high arsenic levels have been reported during periods of low flow (Elbaz-Poulichet et al., 2006). Several studies have evaluated seasonal changes in arsenic levels in groundwater (although these studies have taken place in areas with much more precipitation than in our study area) and several studies assessed only a small number of wells (Savarimuthu et al., 2006; Nadakavukaren et al., 1984; Cheng et al., 2005; Rodriquez et al., 2004; Berg et al., 2001; Van Geen et al., 2002). The results of these studies have been inconsistent, with some wells showing higher arsenic concentrations during the wet season, some showing higher concentrations during the dry season, and

some showing little seasonal change. For example, Nadakavukaren et al. (1984) identified several wells in Oregon in which arsenic concentrations decreased dramatically in the wet season including one well in which arsenic levels fell from over 1000 μg/L during a period of low rainfall to under 400 μg/L during a period of high rainfall. In contrast, in a study of 74 wells in West Bengal, average arsenic concentrations were higher during the monsoon season (906 μg/L) than in the dryer summer season (694 μg/L). The reasons why these large seasonal changes have been seen in some wells is not entirely clear although mechanisms such as dilution by rainfall or changes in redox conditions due to seasonal changes in pumping rates, water movements, or water table depths have been proposed (Tareq et al., 2003; Cheng et al., 2005; Nadakavukaren et al., 1984; Rodriquez et al., 2004). The reasons why past studies have reported varying results are also not known but could be related to geological differences across study areas.

Variability in seasonal arsenic measurements poses consequences regarding the interpretation and frequency of well water measurements. If there is large annual or seasonal variability, epidemiologic studies which use a single well measurement as an approximation for long-term arsenic concentration and exposure may be very inaccurate. In our study, the differences in arsenic concentrations between wet and dry seasons were not statistically significant in any subcategory. These results provide evidence that there is little seasonal variability of arsenic levels in most wells associated with river flow changes or irrigation patterns in our study area and suggest that in our study area a single measurement of arsenic in well water may be a fairly accurate predictor of long-term exposure.

The authors chose river flow instead of rainfall as the predictor of ground water arsenic contamination for several reasons. Previous investigations have suggested that rainfall is not a good predictor of arsenic levels in ground water or surface streams (Tareq et al., 2003; Iwashita and Shimamura, 2003; Ohno et al., 2005). Further, most of the regeneration of groundwater in this region is supplied by river water or irrigation (Maurer and Berger, 2007; Herrera et al., 2000). Additionally, Johnson (2002) and Pettine et al. (1994) demonstrated a concordance between stream flow and arsenic levels in surface streams. In this region of western Nevada, peaks for river flow and rainfall did not occur at similar times. This is likely due to the very low rainfall of the region (approximately 8 in annually) and the large contribution of nearby mountain snow melt to the river supply (NCDC, 2006). Due to the arid climate, the regeneration of groundwater in this region is likely dependent on mountain snow melt rather than rainfall (USGS, 2006). A prior study, from this same data source, has shown a strong correlation between well arsenic concentrations over several years, however, seasonal variability was not assessed (Steinmaus, C., 2005). Other investigations have found similar results supporting the temporal stability of arsenic levels over time (Focazio et al., 2000; Karagas et al., 2001; Ryan et al., 2000; Seiler, 2004). While some studies have suggested that applied irrigation may be a significant contributor to groundwater recharge, some data suggests that in some areas the majority of applied irrigation is consumed by evapotranspiration (Herrera et al., 2000). Our study evaluated this possibility and did not find any significant seasonal impact on arsenic concentrations based on irrigation patterns. This current investigation adds to the body of evidence which suggests that in relatively dry areas such as our study area, arsenic levels in wells are stable over time and do not have significant seasonal variability.

Our results may not be generalizable to other areas. The river flow or rainfall variability in Nevada does not likely compare to the variability in other areas such as Bangladesh in which seasonal monsoons may have a greater impact (Cheng et al., 2005). In this study, months were assigned to wet and dry based on historical river flow and irrigation data. However, there was substantial variability from year to year, and for some of the wells in our study, we used measurements taken from wet and dry seasons from different years. Our database contained too few wells in which arsenic measurements were taken in the same year to perform an analysis including only this subset. Accordingly, we conducted a sub-analysis including only the three driest and three wettest months to emphasize the seasonal differences in river flow that may exist, but found no significant pattern. Similarly, to evaluate the possible impact of year to year differences in river flow on our results, we conducted an additional sub-analysis that included only those wells with measurements taken during years with the highest seasonal river flow variability. Despite emphasizing the river flow to minimize misclassification, there were no significant differences in arsenic concentration. Since our study area covered a large and somewhat diverse geographical area, it is possible that different sources of groundwater recharge predominate for different regions. Nevertheless, in this study, we evaluated two known major sources of groundwater recharge, river flow and applied irrigation, and found no significant seasonal variability.

Additionally, well measurements were used spanning a period from 1982 to 2000. This does not take into account changes in technology and accuracy with which arsenic is measured. The authors believe that the degree of accuracy likely did not have an impact in the overall results. It is possible that at the lower levels and limits of detection there may have been some effect in the 0−10 μg/L category. However, this category had the largest sample size and demonstrated no evidence of statistical significance.

Although we identified no clear change in arsenic concentrations associated with season, large changes in arsenic concentrations were seen over time in some wells. The reason for these changes are unknown but could be due to changes or errors in collection or analytical

procedures, changes in water filter use or pumping rates, or other factors. In this study, we included mostly private domestic wells that were identified only by 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 different wells tapping different aquifers. We attempted to eliminate this possibility by eliminating those addresses with conflicting information on well depth, although information on well depth was not available on all wells in our database. Importantly, as seen in Fig. 2, large changes in arsenic concentration (i.e. >30% change) only occurred in a minority of the wells suggesting that the impact of multiple wells at a single address had little impact on this analysis. The large changes seen in some wells may be due to reasons other than seasonal impacts. If season had a large and wide impact, the authors would expect most changes to be in the same direction. Rather, the large changes that occurred in a few wells demonstrated no pattern. Further, the minor changes that may have occurred as a result of inconsistent sampling are unlikely to mask the wide seasonal variability in arsenic concentration that have been reported in other studies.

Based on the findings of our study, there does not appear to be significant seasonal variability in arsenic levels in well water based on river flow or applied irrigation. This lack of predictable and generalizable seasonal variability in arsenic concentrations in well water could have public health implications. Resources can be geared toward mitigation of problem areas instead of repeated measurements based on general definitions of season. While repeated testing for certain wells undergoing remediation may be warranted, testing based on seasons as defined in our study may not need to be performed to get an accurate assessment of arsenic exposure for the majority of wells. Additionally, this information may be useful to current and future research regarding arsenic measurements and health effects.

References

Ayotte, J.D., Montgomery, D.L., Flanagan, S.M., Robinson, K.W., 2003. Arsenic in groundwater in eastern New England: occurrence, controls, and human health implications. Environ. Sci. Technol. 37, 2075–2083.

Bates, M., Rey, O., Biggs, M., Hopenhayn, C., Moore, L.E., Kalman, D., Steinmaus, C., Smith, A.H., 2004. Case-control study of bladder cancer and exposure to arsenic in Argentina. Am. J. Epidemiol. 159, 381–389.

Berg, M., Tran, H.C., Nguyen, T.C., Pham, H.V., Schertenleib, R., Giger, W., 2001. Arsenic contamination of groundwater and drinking water in Vietnam: a human health threat. Environ. Sci. Technol. 35 (13), 2621–2626.

Cheng, Z., van Geen, A., Seddique, A.A., Ahmed, K.M., 2005. Limited temporal variability of arsenic concentrations in 20 wells monitored for 3 years in Araihazar, Bangladesh. Environ. Sci. Technol. 39 (13), 4759–4766.

Chowdhury, U.K., Biswas, B.K., Chowdhury, T.R., Samanta, G., Mandal, B.K., Basu, G.C., Chanda, C.R., Lodh, D., Saha, K.C., Mukherjee, S.K., Roy, S., Kabir, S., Quamruzzaman, Q., Chakraborti, D., 2000. Groundwater arsenic contamination in Bangladesh and West Bengal, India. Environ. Health Perspect. 108, 393–397.

Crecelius, E.A., Bloom, N.S., Cowan, C.E., Jenne, E.A., 1986. Speciation of selenium and arsenic in natural waters and sediments. Volume 2: Arsenic Speciation, EPRI Report #EA-4641, pp. 2.1–2.28.

Elbaz-Poulichet, F., Siedel, J., Casiot, C., Tisseau-Vuillemin, M.H., 2006. Short term variability of dissolved trace element concentration in the Marne and Seine Rivers near Paris. Sci. Total Environ. 367, 278–287.

Focazio, M.J., Welch, A.H., Watkins, S.A., Helsel, D.R., Horn, M.A., 2000. A retrospective analysis on the occurrence of arsenic in groundwater resources of the United States and limitations in drinking-water-supply characterizations. US Geological Survey Water-Resources Investigation Report, 99-4279.

Frost, F.J., Frank, D., Pierson, K., Woodruff, L., Raasina, B., Davis, R., Davies, J., 1993. A seasonal study of arsenic in groundwater, Snohomish County, Washington, USA. Environ. Geochem. Health 15, 209–214.

Gault, A.G., Polya, D.A., Lythgoe, P.R., 2003. Seasonal variation of total dissolved arsenic and arsenic speciation in a polluted waterway. Environ. Geochem. Health 25, 77–85.

Herrera, N.B., Seiler, R.L., Prudic, D.E., 2000. Conceptual evaluation of ground-water floor and simulated effects of changing irrigation practices on the shallow aquifer in the Fallon and Stillwater areas, Churchill County, Nevada. US Geological Survey, Water-Resources Investigations Report 99-4191, pp. 1–76.

Iwashita, M., Shimamura, T., 2003. Long-term variations in dissolved trace elements in the Sagami River and its tributaries. Japan. Sci. Total Environ. 312, 167–179.

Johnson, A., 2002. A total maximum daily load evaluation for arsenic in the Similkameen River. Washington State Department of Ecology, Publication number 02-03-044, pp. 1–21.

Karagas, M.R., Le, C.X., Morris, S., Blum, J., Lu, X., Spate, V., Carey, M., Stannard, V., Klaue, B., Tosteson, T.D., 2001. Markers of low level arsenic exposure for evaluating human cancer risks in a US population. Int. J. Occup. Med. Environ. Health 14, 171–175.

Kelly, W., Holm, T., Wilson, S., Roadcap, G., 2005. Arsenic in glacial aquifers: sources and geochemical controls. Ground Water 43, 500–510.

Kim, M., Nriagu, J., Haack, S., 2002. Arsenic species and chemistry in groundwater of Southeast Michigan. Environ. Pollut. 120, 379–390.

Lewis, D., Southwick, J., Ouellet-Hellstrom, R., Rench, J., Calderon, R., 1999. Drinking water arsenic in Utah: a cohort mortality study. Environ. Health Perspect. 107, 359–365.

Maher, W., Butler, E., 1988. Arsenic in the marine environment. Appl. Organomet. Chem. 2, 191–214.

Maurer, D.K., Berger, D.L., 2007. Water budgets and potential effects of land and water-use changes for Carson Valley, Douglas County, Nevada, and Alpine County, California. US Geological Survey Scientific Investigations Report 2006-5305, pp. 1–74. ⟨http://pubs.usgs.gov/sir/2006/5305/pdf/sir20065305.pdf⟩.

McLaren, S.J., Kim, N.D., 1995. Evidence for a seasonal fluctuation of arsenic in New Zealand's longest river and the effect of treatment on concentrations in drinking water. Environ. Pollut. 90 (1), 67–73.

Nadakavukaren, J.J., Ingermann, R.L., Jeddeloh, G., Falkowski, S.J., 1984. Seasonal variation of arsenic concentration in well water in Lane County, Oregon. Bull. Environ. Contam. Toxicol. 33, 264–269.

National Climactic Data Center (NCDC), 2006. National Environmental Satellite, Data, and Information Service (NESDIS), National Oceanic and Atmospheric Administration (NOAA), US Department of Commerce.

National Research Council (NRC), 1999. Arsenic in Drinking Water. Subcommittee on Arsenic in Drinking Water, Washington, DC. National Research Council, 1999.

National Research Council (NRC), 2001. Arsenic in drinking water 2001 update. Subcommittee to Update the 1999 Arsenic in Drinking Water Report. Washington, DC. National Research Council.

Nordstrom, D.K., 2002. Public health. Worldwide occurrences of arsenic in ground water. Science 296, 2143–2145.

Ohno, K., Furukawa, A., Hayashi, K., Kamei, T., Magara, Y., 2005. Arsenic contamination of groundwater in Nawabganj, Bangladesh,

focusing on the relationship with other metals and ions. Water Sci. Technol. 52 (8), 87–94.

Olias, M., Nieto, J.M., Sarmiento, A.M., Ceron, J.C., Canovas, C.R., 2004. Seasonal water quality variations in a river affected by acid mine drainage: the Odiel River (southwest Spain). Sci. Total Environ. 333, 267–281.

Peters, S.C., Blum, J.D., Klaue, B., Karagas, M.R., 1999. Arsenic occurrence in New Hampshire drinking water. Environ. Sci. Technol. 33, 1328–1333.

Pettine, M., Camusso, M., Martinotti, W., 1994. Dissolved and particulate transport of arsenic and chromium in the Po River (Italy). Sci. Total Environ. 119, 253–280.

Rodriquez, R., Ramos, J.A., Armienta, A., 2004. Groundwater arsenic variations: the role of local geology and rainfall. Appl. Geochem. 19, 245–250.

Ryan, P.B., Huet, N., MacIntosh, D.L., 2000. Longitudinal investigation of exposure to arsenic, cadmium, and lead in drinking water. Environ. Health Perspect. 108, 731–735.

Sanchez-Rodas, D., Gomez-Ariza, J.L., Giraldez, I., Velasco, A., Morales, E., 2005. Arsenic speciation in river and estuarine waters from Southwest Spain. Sci. Total Environ. 345, 207–217.

Savarimuthu, X., Hira-Smith, M.M., Yuan, Y., von Ehrenstein, O.S., Das, S., Ghosh, N., Guha, D.N., Smith, A.H., 2006. Seasonal variation of arsenic concentration in tube wells in West Bengal, India. J. Health Popul. Nutr. 24, 1–5.

Seiler, R.L., 2004. Temporal changes in water quality at a childhood leukemia cluster. Ground Water 42 (3), 446–455.

Seiler, R.L., Stollenwerk, K.G., Garbarino, J.R., 2005. Factors controlling tungsten concentrations in ground water, Carson Desert, Nevada. Appl. Geochem. 20, 423–441.

Smedley, P.L., Kinniburgh, D.G., 2002. A review of the source, behaviour and distribution of arsenic in natural waters. Appl. Geochem. 17, 517–568.

Steinmaus, C., Yuan, Y., Bates, M.N., Smith, A.H., 2003. Case-control study of bladder cancer and drinking water in arsenic in the western United States. Am. J. Epidemiol. 158, 1193–1201.

Steinmaus, C., Carrigan, K., Kalman, D., Atallah, R., Yuan, Y., Smith, A.H., 2005. Dietary intake and arsenic methylation in a US population. Environ. Health Perspect. 113 (9), 1153–1159.

Steinmaus, C.M., Yuan, Y., Smith, A.H., 2005. The temporal stability of arsenic concentrations in well water in western Nevada. Environ. Res. 99, 164–168.

Tareq, S.M., Safiullah, S., Anawar, H.M., Anawar, H.M., Rahman, M.M., Ishizuka, T., 2003. Arsenic pollution in groundwater: a self-organizing complex geochemical process in the deltaic sedimentary environment, Bangladesh. Sci. Total Environ. 313, 213–226.

United States Environmental Protection Agency (USEPA), 2001. Federal Register, 22 January 2001, vol. 66(14), pp. 6975–7066 ⟨http://www.epa.gov/fedrgstr/EPA-WATER/2001/January/Day-22/w1668.htm⟩.

United States Geological Survey (USGS), 2004. Estimated Use of Water in the United States in 2000. US Geological Survey, Denver, CO ⟨http://water.usgs.gov/pubs/circ/2004/circ1268/⟩.

United States Geological Survey (USGS), 2006. Ground water atlas of the United States: California and Nevada, HA 730-B ⟨http://capp.water.-usgs.gov/gwa/ch_b/B-text1.html⟩ (downloaded May 2006).

United States Geological Survey National Water Information System, 2006. United States Department of the Interior ⟨http://waterda-ta.usgs.gov/nwis⟩.

Van Geen, A., Ahsan, H., Horneman, A.H., Dhar, R.K., Zheng, Y., Hussain, I., Ahmed, K.M., Gelman, A., Stute, M., Simpson, H.J., Wallace, S., Small, C., Parvez, F., Slavkovich, V., Loiacono, N.J., Becker, M., Cheng, Z., Momotaj, H., Shahnewaz, M., Seddique, A.A., Graziano, J.H., 2002. Promotion of well-switching to mitigate the current arsenic crisis in Bangladesh. Bull. World Health Organ. 81, 732–737.

Welch, A.H., Helsel, D.R., Focazio, M.J., Watkins, S.A., 1999. Arsenic in ground water supplies of the United States. In: Chappell, W.R., Abernathy, C.O., Calderon, R.L. (Eds.), Arsenic Exposure and Health Effects: Proceedings of the Third International Conference on Arsenic Exposure and Health Effects, 12–15 July 1998, San Diego, CA. Elsevier Science, New York, pp. 9–17.