Response to Comments on "Limited Temporal Variability of Arsenic Concentration in 20 Wells Monitored for 3 Years in Araihazar, Bangladesh"

The substance of the comments provided by Sengupta et al. (*1*) and Ravenscroft et al. (*2*) is that unwarranted policy recommendations were drawn from the evidence of limited temporal change in groundwater As concentrations observed in wells spanning a wide range of depths and geological settings, albeit within a limited area of Bangladesh. For reasons explained below, we stand by our conclusion that exploitation with hand pumps of those aquifers that are low in As, accompanied by periodic testing, provides the most effective way of rapidly reducing the continued exposure of millions of people to As.

Neither comment challenges the validity of our data obtained from a set of 20 wells used by surrounding villagers throughout the 3-year monitoring period (*3*). The main finding of this study, unprecedented in terms of its combination of duration and temporal resolution, is that the standard deviation of variations in As concentrations over time were below 10 μg/L in 17 of the 20 hand-pumped wells, all of which initially yielded groundwater containing $\leq$50 μg/L As. Given the current lack of realistic alternatives for rapidly reducing As exposure in rural Bangladesh, Sengupta et al. (*1*) and Ravenscroft et al. (*2*) would probably not oppose an expanded use of low-As aquifers in our study area coupled to a monitoring program, even if larger fluctuations and/or the marked increase in As concentrations observed in 3 out of 20 wells are not fully understood. The main concern expressed in both comments appears to be, rather, the extrapolation of our findings over longer time scales and to other affected villages within the Ganges–Brahmaputra–Meghna Delta.

Two misconceptions must be addressed before examining the evidence for spatial or temporal features in the available data. First, we make no claim anywhere in the paper that a depth of 30 m is sufficient to reach orange-brown aquifer material associated with low groundwater As concentrations in the study area, let alone the country at large. We could not agree more with Sengupta et al. (*1*) that the geology of Bangladesh is highly variable and actually made that point ourselves on the basis of particularly dense geo-referenced data of well As concentrations (*4*). The village is the appropriate scale for identifying safe aquifers at depth. Attempts to make prediction on a larger scale will inevitably lead to a target depth beyond what is needed in a large number of villages (*5*).

Second, changes in groundwater As concentration over time must be differentiated from changes in well As with the age of a well. Ravenscroft et al. (*2*) quote several studies including one of our own indicating that, on average, well As concentrations increase with the age of a well in several areas. The trends are statistically significant but highly scattered. We do not dispute these observations and, in our paper that generated the two comments (*3*), provided some evidence that As concentrations rose in a well because of poor construction. Such a highly localized increase in well-water As concentrations due to entrainment of shallow groundwater is very different from the gradual contamination of an entire aquifer. Periodic monitoring using a reliable field kit (*6*) is the way to prevent As exposure caused by a failing well.

To clarify the discussion, we summarized to the best of our knowledge in Table 1 the arsenic monitoring data that is available from Bangladesh, India, and Vietnam. Although the problem of As in groundwater was recognized in West Bengal 20 years ago and in Bangladesh 10 years ago, there is not even today an official long-term monitoring program of a subset of representative tube wells that relies on quality-controlled, laboratory measurements. The oldest relevant data are therefore not based on past sampling but on the more recent documentation of elevated As concentrations (43–1009 μg/L) in 23 samples of groundwater known to have been out of contact with the atmosphere for over 40 years (*7*–*10*). This minimum age estimate is based on the absence in well water of detectable levels of the radioisotope ^{3}H (tritium) produced by atmospheric bomb testing, primarily during the 1950s and 1960s. The implication is that As concentrations were elevated at least in some areas of Bangladesh well before the onset of any large-scale groundwater extraction to supply cities or irrigation.

Although we included in Table 1 all of the data referred to by Sengupta et al. and Ravenscroft et al., our inclination is to discount qualitative statements based on poorly documented data in inaccessible reports. This is because reliable As measurements for groundwater require considerable preparation and skill. In our opinion, the most convincing evidence of a long-term rise in groundwater As concentrations comes from certain districts of West Bengal where Dr. Chakraborti's group has sampled the same wells 5 years apart (*11*, *12*). Unfortunately, no data are available to determine if the rise occurred gradually or suddenly, which might indicate well failure. The trends are troubling, even if the proportion of wells affected is difficult to judge from the information provided.

No reliable time series data spanning more than 3 years, not even two-point comparisons, are available from Bangladesh. Here the most worrisome evidence is that of changes in well As concentrations with well age, as documented independently from data sets composed of 300 000 field kit measurements (*13*) and a total of nearly 10 000 laboratory measurements (*4*, *14*). These trends have been expressed as either an increase in the proportion of wells crossing the 50 μg/L threshold (*13*, *15*) or a modest average increase in well As concentration of <2 μg/L per year (*4*). The evidence cannot be disputed even if here again it is unclear if a significant proportion of these increases could reflect well failure. It is important, however, to keep a sense of perspective. In our opinion, tube wells that tap aquifers that are low in As should remain the focus of remediation efforts even if the groundwater from a fraction of these wells is likely to contain >50 μg/L As 10 years from now. Again, periodic testing that is readily available at the village is critical to identify those failing wells. Testing should be conducted annually and, at least once, during both the wet and the dry season because of growing evidence of seasonally fluctuating As concentrations in some shallow wells (*3*, *16*, *17*).

As both Sengupta et al. (*1*) and Ravenscroft et al. (*2*) would recognize, there is considerable uncertainty about the likely long-term evolution of As concentrations in West Bengal and Bangladesh. The evolution of As concentrations may be quite different in various parts of the delta. It may take another decade of widespread monitoring and precise measurements to define any such trends or lack thereof. Unfortunately, such a monitoring network is still not in place in Bangladesh. What is known is that millions of people throughout the area continue to be exposed to As while living within walking distance of a well that is low in As or drilling distance of a

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TABLE 1. Summary of Reported Arsenic Monitoring Data for Bangladesh, India, and Vietnam

reference	form of publication	type of data	analytical method[a]	data quality[b]	main conclusion	data shown?
Indirect Evidence over Decades						
Aggarwal et al. (*8*)	report	^{3}H and As in 11 samples			Eight samples with significantly elevated arsenic levels do not contain any detectable ^{3}H.	yes
BGS−DPHE (*7*)	report	^{3}H and As in 31 samples			"The finding of very low tritium concentrations (<1 TU) at depth... while at the same time finding high concentrations of arsenic (in 8 wells)... is a strong indication that the arsenic release predates the 1960s."	yes
Zheng et al. (*10*) and Stute et al. (*9*)	*Appl. Geochem.*	^{3}H and As in 40 samples			high arsenic levels of arsenic without detectable ^{3}H (<1 TU; indicates very old water) in 7 wells	yes
DPHE (14); McArthur et al. (*23*)	*Appl. Geochem.*	well age vs As relationship for >2000 wells	HG-ICP-AES or HG-ICP-AFS	adequate	"...for the first ten years of existence, the exceedance for most threshold values of As increases as well-age increases, irrespective of region or threshold."	yes
van Geen et al. (*4*)	*Water Resour. Res.*	well age vs As relationship for 5971 samples	GFAAS	adequate	increase of 16 ± 2 μg/L per decade	yes
Rosenboom (*13*)	report	well age vs As relationship for ∼300 000 wells	field kits	adequate	"...older wells have a higher chance of exceeding the permissible arsenic level (75% for wells older than 25 years, against 65% for all wells)."	yes
Direct Measurements over >2 Years						
SOES−DCH (*19*), cited by BGS−DPHE (*7*)	report	unspecified	unspecified	unknown	"...deep wells that were once arsenic-free are now arsenic-contaminated"	no
Chakraborti et al. (*12*)	conference volume	31 wells sampled in 1995 and 2000	FI-HG-AAS	high	"Out of 31 tube wells in 18 we found increased arsenic concentration. Rest 13 either remained close to previous value (±15%) or decreased." (D. Chakraborti, Personal communication, 2005)	yes
Sengupta et al. (*11*)	conference abstract	unspecified number of wells from 9 arsenic-affected districts of West Bengal sampled in 1997 and 2003.	FI-HG-AAS	high	"...some villages in the 9 arsenic-affected districts of West Bengal where the tube wells, which were safe or very less contaminated, got contaminated with time..."	yes
Direct Measurements over <2 Years						
Burren (*20*), cited by Ravenscroft et al. (*2*)	thesis	unspecified	unspecified	unknown	"...data strongly suggest a trend of increasing arsenic concentration over time."	no
CGWB (*18*), cited by BGS−DPHE (*7*)	book	unspecified	unspecified	unknown	"Monitoring in West Bengal has indicated that arsenic concentrations in tube wells are lowest during the months August−September."	no
Asia Arsenic Network (*17*)	report	5 observation wells at different depths	AAS or field kit	unknown	"...the concentration is generally higher in the rainy season than in the dry season ..."	yes
DPHE (*14*), cited PHED (*24*) pumping test	report	unspecified	unspecified	unknown	"...very slight increases in arsenic toward the end of eight hour pumping tests, though the significance of these very slight increases is unclear. However, the general short-term trend indicates little change."	yes
DPHE (*14*), cited data from 18 District Towns Project	report	6 randomly selected wells	unspecified	unknown	"Of the six wells randomly selected... only one or two appear to show a consistent increase with time, and they are still well below the Bangladesh standard. The other wells appear to show no overall trend to increase or reduce."	yes
Berg et al. (*16*)	*Environ. Sci. Technol.*	68 wells sampled three times in 1999−2000	HG-AAS	adequate	"The highest arsenic concentrations occurred at the rainy season to dry season and the lowest at the end of the dry season"	yes
BGS−DPHE (*7*)	report	32 wells sampled biweekly over 1 year	HG-ICP-AES or HG-ICP-AFS	adequate	"Arsenic concentrations show little notable temporal variation in most of the monitored wells"	yes
van Geen et al. (*21*)	*Bull. W.H.O.*	6 wells sampled monthly for 1 year	HR-ICP-MS	high	"The six currently safe wells that were sampled more frequently over a year showed no indication of significant seasonal fluctuations in arsenic concentrations ..."	yes
van Geen et al. (*22*)	*Bull. W.H.O.*	7 deep wells sampled biweekly for 1 year	HR-ICP-MS	high	"...there were no noticeable seasonal variations in arsenic concentrations."	yes
van Geen et al. (*6*)	*Environ. Sci. Technol.*	344 wells sampled in 2001 and 2003	HR-ICP-MS	high	"No systematic temporal trend can be inferred from the data."	yes

[a] HG-ICP-AES, hydride generation inductively coupled plasma atomic emission spectrometry; HG-ICP-AFS, hydride generation inductively coupled plasma atomic force spectrometry; GFAAS, graphite furnace atomic absorption spectrometry; FI-HG-AAS, flow injection hydride generation atomic absorption spectrometry; HG-AAS, hydride generation atomic absorption spectrometry; HR-ICP-MS, high-resolution inductively coupled plasma mass spectrometry. [b] Reflects our opinion based on the quality-control information that was provided.

safe aquifer. The occasional observation of an increase in As concentrations in wells previously considered to be safe should not deter affected households from continuing to use or install wells tapping aquifers that are low in As. On balance, we therefore remain convinced that periodic monitoring of those wells used for human consumption, and where necessary the installation of monitored community wells, is the best scientific advice to give to policy makers. Imperfect knowledge and understanding of the likely evolution of tube well As concentrations should not be used as an excuse for inaction.

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Zhongqi Cheng and Alexander van Geen

Lamont−Doherty Earth Observatory
Columbia University
Palisades, New York 10964

Ashraf A. Seddique and Kazi M. Ahmed

Geology Department
Dhaka University
Dhaka, Bangladesh

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