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Preface

Arsenic in groundwaters of South-East Asia: With emphasis on Cambodia and Vietnam

Although it is now over a century since Arsenic in well waters was first recognized as a widespread serious health hazard (Ayerza, 1917) and over a quarter of a century since this hazard was recognized in the region of the world most severely impacted Bengal (Saha, 1983; Guha Mazumder et al., 1988) it is only in the last few years that work on analogous occurrences in South-East Asia, notably Vietnam (Berg et al., 2001; Buschmann et al., 2007, 2008; Postma et al., 2007) and Cambodia (Polya et al., 2003, 2005; Stanger et al., 2005; Berg et al., 2007; Buschmann et al., 2007, 2008; Feldman et al., 2007) has been published. This is perhaps surprising given that (i) many of the geological and geographical factors thought to be important in the mobilization of As in shallow aquifers are common to both the Ganges–Brahmaputra–Meghna delta system of Bengal and the Mekong and Red River delta systems of south-east Asia; (ii) south-east Asia is densely populated and increasingly reliant on well waters for irrigation and, to a lesser extent, drinking; and (iii) the human health consequences of chronic exposure to As in well waters at above the 0.01 mg/kg to 0.1 mg/kg level are severe, including debilitating keratoses, gangrene, skin and internal cancers, and, to many sufferers, ultimately death (NRC, 1999, 2001; Smith et al., 2000; Brown, 2004).

A workshop on “Arsenic in Groundwaters of South-East Asia” was therefore organized by Michael Berg (EAWAG, Switzerland) and David Polya (University of Manchester, UK) in Manchester in October 2007 to bring together many of those working on understanding the biogeochemical and other controls on arsenic mobilization in south-east Asian groundwaters and, also, to highlight the humanitarian disaster that will unfold in south-east Asia and (continue to unfold) other regions unless appropriate and prompt mitigation measures are put in place. The understanding of the human health impacts of groundwater As in Bangladesh and West Bengal, in particular, together with the logistical, cultural and political difficulties of implementing comprehensive remediation promptly and robustly, means that studies in such regions outside of south-east Asia are highly relevant and were also included

in the workshop. Conversely, as Polya et al. (2005) and several papers in this volume and elsewhere point out, the relative lack of development of groundwater resources in Cambodia, makes the As bearing aquifers of the Mekong River basin an ideal analogue for those of Bengal and other areas world-wide prior to the massive exploitation of these aquifers for irrigation over the last few decades.

The workshop attracted the majority of the leading research groups working on As in groundwaters specifically in Cambodia and Vietnam, with participants from Vietnam, Cambodia, Laos, Japan, India, Bangladesh, USA, Canada, Australia, New Zealand, Switzerland and over a dozen countries from within the European Union. Globally, however, the field of environmental geochemistry and health regarding As is a very large one (see reviews and some key papers for example from, Das et al., 1996; Bhattacharya et al., 1997; DPHE/BGS/MML, 1999; NRC, 1999, 2001; Smith et al., 2000; Nickson et al., 1998; Ravenscroft et al., 2001; BGS/DPHE, 2001; Chakraborti et al., 2002; Smedley and Kinniburgh, 2002; Harvey et al., 2002; Nordstrom, 2002; Dowling et al., 2002; Oremland and Stolz, 2003; Dixit and Hering, 2003; Van Geen et al., 2003, 2004; Islam et al., 2004; McArthur et al., 2004; Zheng et al., 2004; Brown, 2004; Chakraborti et al., 2004; Guha Mazumder et al., 2005; Charlet and Polya, 2006; Lowers et al., 2007; and references therein), and inevitably many of the researchers in this area, including some of the world's leading authorities did not attend the workshop, which was limited for logistic and financial reasons to around 70 participants (Fig. 1). A thematic issue of “Applied Geochemistry” based on the workshop was therefore proposed to communicate the workshop proceedings more effectively to this wider audience – both directly to researchers and indirectly to key stakeholders with the responsibility, authority and wherewithal to address this important environmental health problem. This editorial provides an overview of this thematic issue published here.

The 21 papers published reflect the major themes of the “Arsenic in Groundwaters of South-East Asia” October



Key to Photo of participants in the Workshop on Arsenic in Groundwaters of SE Asia
29-30 Oct 2007, Manchester, UK

1	Peter Tenscher, CEREGE, France	30	Takaaki Itai, Hiroshima, Japan
2	Lenny Winkel, EAWAG, Switzerland	31	Jasmin Mertens, ETHZ, Switzerland
3	Roy Wogelius, Manchester, UK	32	Stephan Hug, EAWAG, Switzerland
4	Claudia Cascio, De Montfort, UK	33	Bart Van Dongen, Manchester, UK
5	Dave Polya, Manchester, UK	34	Cristina Jimenez, UBB, Romania
6	Debapriya Mondal, Manchester, UK	35	Nora Sutton, Utrecht, The Netherlands
7	Chris Parsons, UJF- Grenoble, France	36	Scott Fendorf, Stanford, USA
8	David Vaughan, Manchester, UK	37	Michael Lawson, Manchester, UK
9	Ioannis Katsoyiannis, EAWAG, Switzerland	38	Konstantina Tyrolova, TUC, Greece
10	Helen Rowland, EAWAG, Switzerland	39	Yanchun Zhang, Utrecht, Manchester
11	Ed Gilligan, ACF, Cambodia	40	Johanna Buschmann, EAWAG, Switzerland
12	Ben Bostick, Dartmouth, USA	41	Rohit Bhagwat, Manchester, UK
13	Shawn Benner, Boise State, USA	42	Bouthan Bounvilay, NUOL, Lao PDR
14	Andrew Gault, Ottawa, Canada	43	Elisabeth Eiche, Karlsruhe, Germany
15	Soren Jessen, IER/TUD, Denmark	44	Michael Berg, EAWAG, Switzerland
16	Marina Hery, Manchester, UK	45	Caroline Stengel, EAWAG, Switzerland
17	Enoma Omoregie, Manchester, UK	46	Mickey Samspon, RDIC, Cambodia
18	Babek Shafei, Utrecht, The Netherlands	47	Valliyappan Thinnappan, Manchester, UK
19	Barbara Casentini, TUC, Greece	48	Claudia hohmann, Tuebingen, Germany
20	Geerke Floor, Girona, Spain	49	Linda Robert, EAWAG, Switzerland
21	Adrien Mestrot, Aberdeem UK	50	Lex Van Geen, Columbia, USA
22	Trang Thi Kim Pham, CETASD, Hanoi, Vietnam	51	Ashraf Seddique, Osaka, Japan
23	Flemming Larsen, IER/TUD, Denamrk	52	Yoshio Takahashi, Hiroshima, Japan
24	Chea Eliyan, RUPP, Cambodia	53	Laurent Charlet, UJF Grenoble, France
25	Charlotte Sparrenbom, Malmo, Sweden	54	Pham Quy Nhan, Hanoi, Vietnam
26	Julia Leventon, CEU, Hungary	55	Zheng Zhou, Manchester, UK
27	Rich Pancost, Bristol, UK	56	Zahid Aziz, Columbia, USA
28	Dieke Postma, IER/TUD, Denmark	57	Archimedes, Sculpture by Thompson Dagnall
29	Aimee Hegan, JRC-Ispra, Italy		

Fig. 1. Participants in the Joint EAWAG/University of Manchester Workshop on Arsenic in Groundwaters of South–East Asia with Emphasis on Cambodia & Vietnam, Manchester 29–30 October 2007. Key below. Photo: Joyce McBeth.

2007 Workshop, namely: key challenges in arsenic biogeochemistry; practical issues of fieldwork and laboratory

investigations; exposure routes and human health impacts; and remediation and policy responses. The key paper

on policy response and health impacts in Cambodia is that of Sampson et al. Modeled health impacts attributable to As in groundwater are provided by Mondal et al. and Mondal and Polya, whilst geostatistical modeling of the spatial distribution of As in shallow groundwaters is presented by Rodríguez-Lado et al. and Winkel et al. The biggest group of papers in this volume address controls on the mobilization of As through field studies in Cambodia (Rowland et al.; Van Dongen et al.; Kocar et al.; Benner et al.; Quinsall et al.), Vietnam (Larsen et al.; Jessen et al.; Norrman et al.; Eiche et al.) and Bangladesh (Itai et al.), whilst detailed laboratory studies of microbiological and mineralogical controls on As mobility are provided by Akai et al., Thinnappan et al., Saunders et al. and Hery et al. Key aspects of new or improved field sampling and laboratory techniques or combinations of techniques are highlighted by Radloff et al., Mitsunobu et al., and lastly Van Geen et al., whose needle-sampler is revolutionizing the rapid acquisition of groundwater samples with associated host sediments.

1. Policy response and health impacts in Cambodia

Sampson et al. calculate that over 100,000 people are at high risk of chronic As exposure in Cambodia and present what is understood to be the first documentary evidence of arsenicosis in Cambodia published in the scientific literature. Whilst the symptoms of arsenicosis are widely assumed to develop only after 8–10 a of exposure, such symptoms have been observed in Cambodia by Sampson et al. in populations exposed to high As water for as little as 3 a – it is speculated that poor nutrition and other factors related to poor socioeconomic status may be important in this regard. Well water As concentrations as high as 3500 µg/L (compared to the Cambodian Standard of 50 µg/L) were found. Identification of further regions at risk and educating impacted population and those with responsibilities for installing wells and ensuring the quality of well waters is clearly of great importance. Sampson et al. further highlight the need to achieve better coordination between government and non-government bodies involved in the water supply and treatment sector in the country.

2. Modeled groundwater arsenic attributable health impacts

Where remediation of As-bearing drinking water supplies by government or other bodies is taking place, it is self-evident that human exposure to As from other routes, particularly such as eating rice grown in fields irrigated with As-rich well waters (Williams et al., 2007; Heikens et al., 2007; Meharg et al., 2008, and references therein), will become more important in relative terms. Using Monte Carlo simulation methods, Mondal and Polya quantify the relative importance of drinking water and rice exposure routes in an As-impacted area of West Bengal – they show that for this area, drinking water, raw rice and the cooking of rice contribute 48%, 44% and 8% respectively of the median As burden. The implications of this work are that (i) small reductions in As exposure can be achieved

through effectively educating those exposed regarding rice cooking methods; and (ii) complete remediation of high As drinking water supplies would, on average, only remove about half the human exposure to As in this area.

Mondal et al. compare groundwater As-attributable excess disease burden due to internal cancers by two different methods – broadly comparable to the methods used by Yu et al. (2003) and Howard et al. (2006, 2007) and those used by Lokuge et al. (2004) and Adamson and Polya (2007). Their results indicate that lack of detailed consideration of confounding factors such as genetic polymorphisms, smoking and dietary habits, and, in particular, exposure to As through other routes, notably ingestion of As-bearing rice, may significantly impact the accuracy of the results obtained by either method.

3. Geostatistical modeling of spatial distribution of groundwater arsenic

Rodríguez-Lado et al. modeled the As concentration in shallow groundwater in Cambodia using 1329 georeferenced water samples collected during the period 1999–2004 from wells between 16 m and 100 m depth using block regression-kriging on the log transformed As measurements. The regression analysis revealed that there is a good correlation between topographic environmental variables and the content of As in groundwater. Indeed the use of highly spatially resolved auxiliary variables derived from satellite images has enabled these authors to produce a groundwater As hazard map with a higher spatial resolution than any hitherto produced for South-East Asia. Importantly, the studies also map out spatially-dependent uncertainties in the model – these arise in part from local-scale heterogeneities of groundwater As concentration, measurement and reporting errors and from the uneven distribution of sampling – not only as a function of location but also in parameter space – this provides clear criteria for prioritisation for further sampling aimed at reducing model uncertainties.

Winkel et al. present the results of a groundwater survey conducted in South Sumatra, Indonesia, an area predicted to be vulnerable to elevated levels of As in groundwater (Winkel et al., 2008), but before now there was a dearth of data on the subject. Five distinct types of groundwater were identified, with the highest levels of dissolved As found in groundwater abstracted from organic-rich Holocene horizons. Although the magnitude of As enrichment was moderate (maximum of 65 µg/L) in relation to that seen elsewhere in Southeast Asia, the presence of elevated levels of As confirms the authors' predictions that the area may host As-bearing groundwaters and the lack of data regarding this issue in Sumatra makes this study particularly timely.

4. Field studies of high arsenic aquifers in Cambodia

Rowland et al. analysed groundwaters in the Kandal Province of Cambodia, where they found waters with comparable geochemistry to the As-rich groundwaters of West Bengal. They suggested that As is released predominantly via the microbially mediated reductive dissolution of As

bearing Fe(III) oxides. The presence of elevated As in waters with short aquifer residence times highlights the possible vulnerability of these aquifers to the influx of surface derived waters, providing an additional source of labile organic C that could exacerbate As release by stimulating microbial activity.

Van Dongen et al. conducted sedimentary radiocarbon measurements in conjunction with organic geochemical analyses of the saturated hydrocarbon fractions extracted from sediments collected from As-impacted aquifers in Cambodia. Their observed biomarker distribution patterns, e.g. of hopanes, steranes and *n*-alkanes, are in agreement with previous analyses (Rowland et al., 2006, 2007) and showed that the organic matter in a given sedimentary horizon likely derive from a variety of sources including naturally occurring petroleum. They suggest that petroleum derived organic matter in aquifers in which microbially mediated As release takes place may occur at a much wider range of geographical locations than previously thought.

In an impressively detailed field study carried out over a number of years, Kocar et al. show that high As groundwaters in a field site near the Mekong River downstream of Phnom Penh, Cambodia are typically associated with high aqueous Fe(II), NH_4^+ and organic C and these conditions are most evident in sediments underlying permanent wetland environments, for example within oxbow channels. Their data are consistent with models of As mobilization through reductive dissolution of As-bearing Fe(III) hydroxide phases and/or reduction of As(V) to As(III) coupled with oxidation of labile organic C. They further suggest that much of the As mobilization takes place near the surface where sediments become anaerobic. The rates of As mobilization are linked to the rates of deposition of As-bearing sediments over periods of 100–1000 s of years.

In a twin paper, Benner et al. provide detailed measurements and a substantive numerical model of the groundwater flow patterns at the same site as studied by Kocar et al. They note that the net groundwater flow direction is from wetlands to the Mekong River but that the magnitude and even the direction of this flow is highly dependent upon the season – with the flow reversing during the monsoon season. They calculate net groundwater flow velocities of 0.04–0.4 m/a downward through the capping upper clay aquitard and 1–13 m/a horizontally within the sand aquifer, producing aquifer residence times on the order 100–1000 a. Their modeling suggests that shallow (2–10 m) sediments are an important As source. Lastly, both Kocar et al. and Benner et al. highlight the importance of their study site as a model for other shallow aquifer systems in south and south-east Asia prior to the development of massive groundwater-based irrigation schemes.

Quicksall et al. investigated the coupling of sedimentological and geochemical factors controlling the extent and spatial distribution of groundwater As in an avulsed scroll bar sequence in the Mekong River delta in Cambodia. Utilising a remarkable set of satellite images from over the last several decades, Quicksall and his co-workers have traced substantial geomorphological changes including the creation and docking of river islands and gradual and more sudden river channel movements. They contrast scroll

bar sequences, characterized by rapid burial of organic matter and subsequent reduction of Fe and mobilization of As into hosted groundwaters, with older sediments outside of the scrollbar sequences, where the availability of SO_4^{2-} has resulted in the development of Fe sulfides, capable of sequestering As and thereby leading to lower groundwater As concentrations. The Quicksall et al. paper very elegantly highlights the importance of sedimentology in controlling Fe and S mineral transformations and hence the mobility of As in sediments formed in different depositional environments.

5. Field studies of high arsenic aquifers in Vietnam

Larsen et al. have studied recharge processes and surface water–groundwater interactions in a shallow Holocene aquifer in the Red River flood plan near Hanoi, Vietnam through the installation and monitoring of over 200 piezometers. They observed groundwater patterns similar to those noted by Benner et al. and Kocar et al. for the Mekong, with net regional groundwater flow towards the Red River, but a reversal or stalling of the flow during the monsoon season. Larsen et al. further note seasonal differences in the nature of aquifer recharge – predominately from perched water tables in the dry season but from highly permeable bank sediments in the monsoon season. They calculate a transient numerical model of the groundwater flow yields an average recharge rate of 0.06–0.1 m/a through the confining clay, and a total recharge of approximately 0.2 m/a was estimated from $^3\text{H}/^3\text{He}$ groundwater dating. The thickness of the confining clay is shown to be a major control on not only the rate of recharge but the rate of transport of electron acceptors (O_2 , NO_3^- and SO_4^{2-}) into the aquifer – this results in oxic zones with low As concentrations ($<1 \mu\text{g/L}$) where the clay is thin (down to 2 m), but anoxic zones with high As concentrations (up to $550 \mu\text{g/L}$) where the clay layer is thick (up to 10 m) Where the clay layer is thin, an up to 2 m thick oxic zone develops in the shallow aquifer. Larsen et al. calculate rates of mobilization, and the rate of mass transfer of As to the Red River – a figure they estimate to be around 0.01% of the total As remaining in the Holocene sand aquifers.

In the same area, Jessen et al. provide a large scale (over a 45 km transect) geochemical and geophysical study of Holocene and Pleistocene sediments. As in many other parts of the world, they found generally low As concentrations in older yellowish colored Late Pleistocene sediments, with higher As concentrations being generally found in the younger and typically more reducing Holocene sediments. They present evidence for trapped seawater in sediments and propose that sulfide derived from the reduction of marine SO_4^{2-} and forming secondary Fe sulfides plays an important role in controlling groundwater As concentrations.

Norrman et al. outline a study of a recently installed well field at Nam Du, south of Hanoi City. They found contrasting recharge mechanisms for the Holocene and Pleistocene aquifers. Arsenic sourced from within the Holocene aquifer was also thought to contribute to elevated As concentrations in the Pleistocene where this was immediately down hydraulic gradient, a finding which

is consistent with the study of Berg et al. (2008). They make a number of recommendations for drinking water suppliers regarding: (a) implementation of a long-term monitoring program, (b) implementation of alternative water treatment technologies; and (c) consideration of an alternative drinking water source.

Eiche et al. investigated the processes that are behind the genesis of As-rich groundwaters in the Red River Delta near Hanoi, Vietnam, placing particular emphasis on the mechanisms that give rise to the patchy distribution of groundwater As concentrations observed at two sites just 700 m apart. The key difference between the two sites appears to be the aquifer redox state, with the elevated dissolved Fe, NH_4^+ , HCO_3^- , P and mixed Fe(II/III) valence oxyhydroxides of the high-As site indicative of As mobilization by microbially induced reductive dissolution of ferric oxyhydroxides. The (bio)availability of natural organic matter is postulated to be the primary reason for the variable As content of the groundwaters.

6. Field studies of high arsenic aquifers in Bangladesh

Itai et al. describe a geochemical and hydrological study of high As groundwater in Sonargaon, in mid-eastern Bangladesh. High As groundwater was found in the Holocene unconfined aquifer but not in the Pleistocene aquifer. Groundwaters in the Holocene aquifer were of the Ca–Mg– HCO_3 type with major solutes derived from chemical weathering of detrital minerals such as plagioclase and biotite. Indeed, the authors interpret the geochemical data presented in the paper to suggest that chemical weathering of biotite and/or other mafic minerals may represent an important source of As to groundwaters. In particular, the inter-seasonal variation of dissolved Fe but not so much for dissolved As suggests to them that reductive dissolution of Fe(III)–O–H phases is unlikely to be only mechanism contributing to As mobilization in these aquifers.

7. Microbial and mineralogical processes controlling arsenic mobility

Akai et al. employed detailed cellular phospholipid fatty acid (PLFA) analysis coupled with a 16S rDNA analysis to suggest the presence of SO_4 -reducing and Fe-reducing bacteria in natural sediments in Bangladesh. Based on the analyses, they suggested that combined microbial processes of SO_4 reduction to generate anaerobic conditions and Fe reduction to co-reduce As are important biogeochemical factors for As release in the Bangladesh sediments.

Thinnappan et al. studied the reactivity of As(V) with vivianite, which is potentially an important sink for As in some shallow reducing groundwater systems. Various experiments such as titration, dissolution rate determination, adsorption of As(V), and X-ray photoelectron spectroscopy have been carried out to investigate the reactivity of vivianite with As(V). At ambient temperature and pressure, the ZPC of vivianite was determined to be around 5.3 and the extent of adsorption of As(V) at pHs significantly less acidic than this suggested that the presence of around just 0.1% or 0.2% vivianite in an aquifer could play a major role in removing As from groundwater.

Saunders et al. report new data of field bioremediation experiments and geochemical modeling to illustrate the principal geochemical behavior of As in anaerobic groundwaters. They concluded that, when anaerobic bacterial metabolism is optimized by providing both electron donors and acceptors, As is mobile under Fe-reducing conditions, immobile under SO_4 -reducing conditions, and arsenian pyrite is the likely stable mineral phase formed under SO_4 -reducing conditions, instead of pure As-S phases such as realgar or orpiment.

Although the reduction of As(V) to As(III) by As-respiring anaerobic bacteria has been widely suggested to be a critical step in the mobilization of As in shallow reducing aquifers (Islam et al., 2004) including in Cambodia (Pederick et al., 2007; Lear et al., 2007), hitherto there has been little information published as to the identity of the bacteria involved. Hery et al. describe stable isotope probing (SIP) techniques using ^{13}C -labelled acetate amended microcosms to target DNA from the active microbial fraction. *Sulfurospirillum* and *Geobacter* are implicated in As(V) respiration in such studies by the phylogenetic analysis of the *arrA* gene, which is associated with respiration of As(V).

8. New or improved field and laboratory techniques

Radloff et al. present a useful laboratory comparison between common sterilization treatments employed to generate abiotic systems utilized as controls in microcosm incubations that are often used to determine As mobilization under different biogeochemical regimes. Using Pleistocene sediments from Bangladesh, they found that autoclaving and low dose antibiotics were unsuitable sterilization procedures, which led to compositional changes in the microcosm slurry, and ineffective inhibition of microbial activity, respectively. Gamma irradiation and a higher antibiotic dose were both found to satisfactorily suppress microbial activity while maintaining the chemical and mineralogical integrity of the system. The authors also highlight the problem of sediment heterogeneity in such studies and the need to carefully interpret the results of microcosm experiments with this in mind.

Mitsunobu et al. used X-ray absorption fine structure (XAFS) and Mössbauer spectroscopies to characterize Fe(III) (hydr)oxides in soils near Ichinokawa mine, Japan. Structural changes in the ferric (hydr)oxides with depth were correlated with the release of As into pore-water. The persistence of ferrihydrite over the depth range investigated, together with concomitant increases in total As and in As(III)/As(V) suggested to the authors that As mobility in these mine soils was largely controlled by the redox transformations of As(V) to As(III) rather than reductive dissolution of Fe(III) (hydr)oxides.

Van Geen et al. present “needle sampler” data for simultaneously collected groundwater and particulate material obtained from Bangladesh, Nepal, Vietnam and India. Using this extensive dataset they found a relationship between dissolved As and P-extractable As from the particulate phase in the Bangladesh samples, interpreted as an adsorptive equilibrium. While such a relationship was not observed for samples collected elsewhere, the

bulk of the analyses could be described by a K_d within the range 4–40 mL/g. Based on this, the authors estimate that such Holocene aquifers have been, or will be, flushed of their initial dissolved As content some 0.5–5 ka subsequent to their deposition. While such a calculation has considerable uncertainty, this empirical approach may be a useful tool to aid understanding of As mobilization, in Bangladesh and elsewhere in world.

9. Discussion and conclusions

The importance of the south–east Asian region as a laboratory for improving understanding of the origins and impacts of hazardous As-bearing shallow aquifers is clearly illustrated not only by the papers in this volume, but also the recent published articles by [Feldman et al. \(2007\)](#), [Gault et al. \(2008\)](#) and [Polizzotto et al. \(2008\)](#), the latter article in “Nature” firmly establishing Cambodia as a key location to observe the hydrogeochemistry and hydrology of shallow reducing aquifers relatively undisturbed by human activity, particularly through irrigation pumping—such a field area is particularly relevant given the recent theories proposed by [Harvey et al. \(2002, 2006\)](#) and the difficulties they highlight in carrying out investigations in areas, such as much of Bangladesh, where massive abstraction of groundwater has been taking place for decades and the hydrological systems have consequently been severely disturbed. Although Vietnam is largely irrigating with surface water, a study by [Berg et al. \(2008\)](#) report that 100 a of pumping deep groundwater for the public water supply of Hanoi (Vietnam) has likely promoted hazardous As enrichment of the deep Pleistocene aquifer.

Besides Cambodia, the lower Mekong delta (Southern Vietnam) and the Red River delta (Northern Vietnam) little is currently known about other Southeast Asian areas with the potential for high As groundwater hazard. [Winkel et al. \(2008\)](#) in an article published in “Nature Geoscience” present new maps for much of Southeast Asia pinpointing areas at risk of groundwater As concentrations exceeding 10 µg/L. Besides a good match with the spatial distribution of known As enrichment these maps clearly indicate elevated risks in Myanmar, Thailand and Sumatra where groundwater studies are scarce or non-existent. The same authors produced a global model identifying regions of potential As contamination in groundwater resulting from reducing and high-pH/oxidizing aquifer conditions, using a novel statistical procedure ([Amini et al., 2008](#)). Such prediction maps are a valuable and resource-saving tool that can guide households at risk of As exposure, and scientists and policy-makers to initiate early mitigation measures to protect the people from As-related health problems as well as to efficiently guide water resource management.

It is hoped that all this activity will encourage further workers not just into groundwater As research but also other environmental issues in Indo–China.

As Sampson, from the Cambodia-based NGO RDIC, pointed out in his interview on the BBC World Service Health Check radio programme in November 2007, wells continue to be installed in Cambodia in areas of known high As hazard. Similar well installations are taking place in many other parts of the world, including Bangladesh.

Thus, perhaps most importantly, it is hoped that this volume will serve to further highlight the massive humanitarian crisis evolving in south–east Asia and in other parts of the world where groundwater As hazard remains to be comprehensively addressed. It is hoped that this volume will contribute to provoking the appropriate agencies to take further heed of sound scientific advice and, where appropriate, to provide more thoughtful types of aid.

Notwithstanding the significant contributions made in this volume there is much that is still not understood about origin and health impacts of groundwater As and what should be done about it. [Press et al. \(2007\)](#) outlines just one promising approach of simultaneously studying the sediment/water transfer of chemical components with contrasting redox, pH and ionic strength dependent geochemistries. The forthcoming AGU Chapman Conference on Arsenic in Shallow Groundwaters, organized by Scott Fendorf and Lex Van Geen and to be held in March 2009 in Siem Reap, near Cambodia’s Angkor Wat, will systematically highlight many of biogeochemical, sedimentological and hydrological processes that require further research.

Quantification of As exposure to different groups remains an area worthy of further rigorous detailed field-based studies. Though not a particular focus of this issue, there also remains much uncertainty about dose–response relationships for many As-attributable diseases for those exposed to drinking water As concentrations much less than 100 µg/L, whilst recent studies by [Chaudhuri et al. \(2006\)](#) and [Ahsan et al. \(2007\)](#), amongst others, highlight the potential importance of genetic controls on individuals’ susceptibility to As-attributable diseases for a given level of exposure. Whilst risk substitution arising from some types of mitigation is quite properly a matter for serious concern, the relative magnitude of As-attributable health risks and health-risks arising from water-borne pathogens from various types of (improved or otherwise) water supply remain poorly quantified ([Adamson and Polya, 2007](#)) – indeed [Esrey \(1996\)](#) suggests sanitation and end-user practices are considerably more important than water supply quality in controlling diarrheal prevalence (which might be used as a crude proxy for water-borne pathogen attributable health risks) in many of the countries seriously impacted by high As groundwater. It is clear that there is still much research to be done on all of hazard mapping and prediction based on robust models of processes, health risk assessments and remediation/mitigation policies and execution.

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