Chapter 8

Sustainable arsenic mitigation – from field trials to implementation for control of arsenic in drinking water supplies in Bangladesh

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8.1 INTRODUCTION

The widespread occurrence of natural arsenic (As) in groundwater in Bangladesh (Figure 8.1) and its landscape scale of exposure have drastically reduced safe water access across the country (Chowdhury & Jakariya, 1999; Mukherjee & Bhattacharya, 2001; van Geen *et al*. 2002; Ahmed *et al*. 2004; Ahmed *et al*. 2006; Rahman *et al*. 2009; Ahmed & Bhattacharya, 2014; Chakraborty *et al*. 2015; Bhattacharya *et al*. 2016). Since the discovery of arsenic in groundwater in the country in 1993, there has been limited success in overall access to safe drinking water and tens of millions of people are still exposed to As concentrations above the Bangladesh drinking water standard (BDWS; 50 µg/L) (BDWS, 1997) which is even 5 times higher than the WHO guideline (10 µg/L) (WHO, 2004, 2011). The toxic effects of long-term exposure to As, a well known carcinogen, from drinking water are commonly manifested as skin disorders such as leuco-melanosis, melanosis, keratosis, gangrene and lung, kidney and bladder cancer, as well as several other non-carcinogenic

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health effects (Smith *et al.* 2000; Guha Mazumder *et al.* 2000; Yu & Ahsan, 2004; Kapaj *et al.* 2006; Smith & Steinmaus, 2009; Argos *et al.* 2010; Parvez *et al.* 2013, 2016). The magnitude of the crisis will depend on the rate at which mitigation programmes are implemented (Kabir & Howard, 2007) and at present the main challenge is to develop a sustainable and cost-efficient mitigation option that will be adopted by the people for scaling up safe water access (Jakariya *et al.* 2003, 2005, 2007; van Geen *et al.* 2002, 2003; Hoque *et al.* 2004; von Brömssen *et al.* 2007; Bundschuh *et al.* 2010; Inauen *et al.* 2013; Hossain *et al.* 2014; SASMIT, 2014).

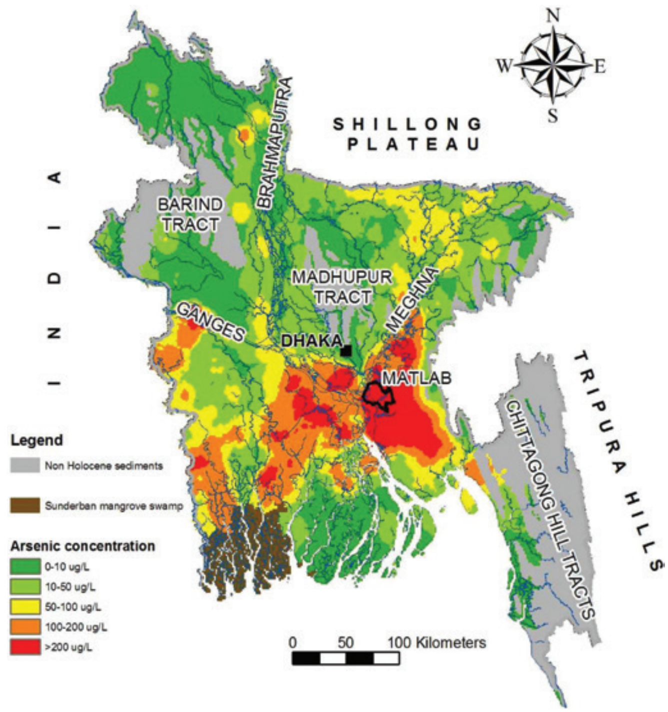

Figure 8.1 Distribution of arsenic in groundwater of Bangladesh showing the location of Matlab as a hotspot and the SASMIT study area. (Map produced by KTH-International Groundwater Arsenic Research Group and referred from von Brömssen *et al.* 2007; Nriagu *et al.* 2007.)

This chapter provides an overview on how the SASMIT (Sustainable Arsenic Mitigation) study was conducted, developed a strategy and applied to enhance safe water access in arsenic affected areas. SASMIT is an action research project that has developed a community based and cost efficient strategy for installation of safe drinking water tubewells in Bangladesh where arsenic is a major contaminant in groundwater. The installations are optimised on the basis of the demand for safe water among the underserved segments of the society as well as increased knowledge of local hydrogeological settings. The text in this chapter is to a substantial extent based upon the unpublished and published outputs of the SASMIT study, including the PhD thesis of the lead author (Hossain, 2015b) and publications written by the co-authors including SASMIT (2014), Hossain *et al.* (2014), Bhattacharya *et al.* (2014, 2015, 2016).

During the last two decades, source and distribution of arsenic (As) in the groundwater and the process of mobilization has been understood to a major extent (Mukherjee & Bhattacharya, 2001; Bhattacharya *et al*. 1997, 2001, 2002a, b; Nickson *et al*. 1998; Harvey *et al*. 2002; Ahmed *et al*. 2004; Islam *et al*. 2004; Zheng *et al*. 2004; McArthur *et al*. 2004; Saunders *et al*. 2005; Harvey *et al*. 2006; Hasan *et al*. 2007; von Brömssen *et al*. 2007, 2008; Mukherjee *et al*. 2008a, b; Polizzotto *et al*. 2008; Polya & Charlet, 2009; Polya & Lawson, 2015), but there has been very limited country wide success in the field of As mitigation measures in Bangladesh (van Geen *et al*. 2002; Jakariya *et al*. 2003, 2005; Ahmed & Bhattacharya, 2014; Hossain *et al*. 2015). The limited progress in arsenic mitigation is attributed to:

- limited involvement of the local community to take their own initiative due to lack of suitable methods to identify the safe aquifers and installation of their own wells at relatively low costs
- dependence on government and other NGOs for arsenic safe wells
- inadequate understanding of local geological and hydrogeological constraints
- unplanned development/installations by different agencies where sustainability is not considered and/or assessed

Countrywide in Bangladesh, more than 10 million tubewells provide access to drinking water to the people, although a great proportion of these wells contain As considerably higher than the drinking water guideline of WHO (10 µg/L) and even the Bangladesh Drinking Water Standard (50 µg/L) (BGS/DPHE, 2001; BBS/UNICEF, 2011). Various options have been deployed for arsenic mitigation both at household and community scales over the past two decades. These options include As-removal filters (ARF), rainwater harvesters (RWH), pond sand filters (PSF), dug wells (DW), hand tubewells (HTW) targeted at depths up to 100 m, as well as deep tube wells (DTW) mostly installed at depths of 200–250 m (Jakariya *et al*. 2005, 2007).

The Swedish International Development Cooperation Agency (Sida)-SASMIT project was conceived by KTH Royal Institute of Technology (KTH-International Groundwater Arsenic Research Group, 2007) together with the Department of Geology, University of Dhaka, NGO Forum for Public Health, Bangladesh and Ramböll Sweden AB, to develop a sustainable mitigation strategy, that rural and disadvantaged community can adopt and implement by themselves. As a part of the SASMIT project, all the options were assessed on the basis of their: (i) acceptability by local community, (ii) technical viability and (iii) their socio-economic implications. Outcomes of this survey, revealed low community acceptance for many of the options, except the As-safe tubewells as an acceptable source of safe drinking water acceptable to communities over the major part of the country (Jakariya *et al*. 2005, 2007; Kabir & Howard, 2006; Hoque *et al*. 2004; Ahmed *et al*. 2006; Hossain *et al*. 2014, 2015). However, drilling to depths beyond 100 m is difficult through the locally available hand-percussion techniques. The SASMIT project was conceived to develop, systematize and operationalize an approach to identify and target the safe aquifers, considering both hydrogeological suitability and social aspects for tubewell installation to provide safe drinking water to communities exposed to elevated arsenic at low cost. SASMIT also recognized the role of local driller community as the main driving force for installation of tubewells, as majority of tubewells (>90%) in the country are installed privately by local drillers (SASMIT, 2014). The SASMIT project thus also aimed to improve the indigenous skills of the driller community to target safe aquifers for tubewell installation and develop their entrepreneurship.

8.2 THE SASMIT ACTION RESEARCH AND IMPLEMENTATION

8.2.1 Assessing available safe water options

Various alternative drinking water options were provided in the Matlab area, during the Sida supported-AsMat (Arsenic in Matlab) project (2001–2006) (AsMat Report, 2007). These options were evaluated through social survey in the project intervention area (SASMIT, 2014; Hossain *et al*. 2015). Tubewells are the most preferred and accepted source of safe drinking water especially to women and children, mainly due to ease of installation, operation, availability of water and maintenance (Figure 8.2). The proportion of safe wells is very limited relative to the overall demand, as the cost for deeper tubewell installation is not affordable by the poor and disadvantaged population (SASMIT, 2014; Hossain *et al.* 2015).

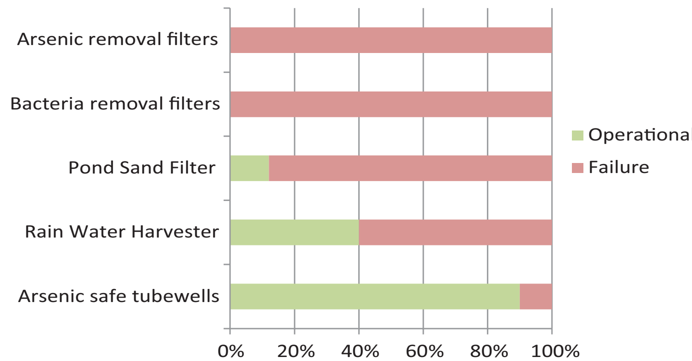

Figure 8.2 Performance analysis on different options deployed for arsenic mitigation in the Matlab area of Bangladesh (SASMIT, 2014).

8.2.2 Perception of local tubewell drillers and practice for tubewell installation

Tubewell technology was first introduced in Bangladesh (the erstwhile East Pakistan) in 1970 primarily for agricultural development (World Bank, 1970). However, there has been a steady growth of tubewells as source of drinking water supply through interventions by the governmental and non-governmental agencies and 90% of the estimated 10 million tubewells in Bangladesh are installed by tubewell drillers, through the initiatives of the local community and recognized as the main driving force for installation of safe tubewells (Jonsson & Lundell, 2004; von Brömssen *et al.* 2005, 2007). With growing demand for groundwater exploitation for drinking water supply both in rural and urban Bangladesh, it will be increasingly important that the local tubewell drillers target safe aquifers for drinking water supplies. The drillers commonly categorize the sediments into four colors namely: black, white, red, and off-white. Based on an earlier study in Matab, Bangladesh (von Brömssen *et al.* 2007), perception of sediment color by the local drillers, led to the postulation of a four color hypothesis. The four color hypothesis (Figure 8.3) indicates that arsenic risk varies with the sediment color, being highest with the black color sediments and gradually reduces towards red. The relation between sediment color and concentration of As in groundwater was validated through a rigorous hydrogeological investigation, sediment characterization, and water quality monitoring and the results have been used to develop a sediment color tool to be used by the tubewell drillers for installation of shallow tubewells. It is important to note that a number of studies carried out in different parts of the Bangladesh and West Bengal (van Geen *et al.* 2003; Jonsson & Lundell, 2004; McArthur *et al.* 2004; Stollenwerk *et al.* 2007; Pal *et al.* 2008, 2009; Hossain *et al.* 2010; Hug *et al.* 2011; Datta *et al.* 2011; Biswas *et al.* 2012; Hossain *et al.* 2014) have indicated similar findings.

8.2.3 Two innovations for installation of safe tubewells

8.2.3.1 Sediment Color Tool for targeting As-safe aquifers at shallow depths

For characterization of sub-surface sediments and installation of piezometers to monitor water quality, test borings were done using the available local technology in 15 locations spread over 410 km^2 area of SASMIT project area in Matlab. Sediments were sampled from each 1.5 m (5 ft) section and were characterized by visual inspection for documentation and preparation of lithologs. Targeting shallow, intermediate-deep and deep aquifers (in relative terms) and also sediments of varying colors, 78 depth-specific piezometers were installed in 15 nests (Figure 8.4). In addition, secondary data reflecting the depths of As peaks in groundwater and water table fluctuation were also taken into consideration.

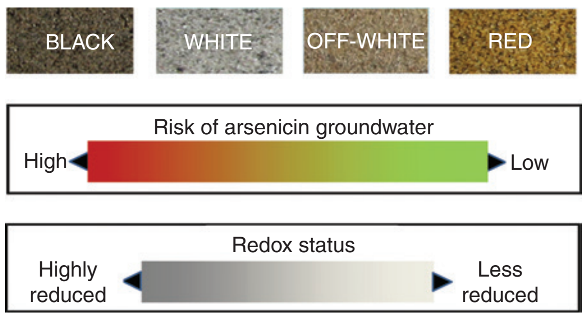

Figure 8.3 The four sand color perceived by the local drillers with corresponding risks of elevated concentration of As in water with varying redox (adapted from von Brömssen *et al.* 2007).

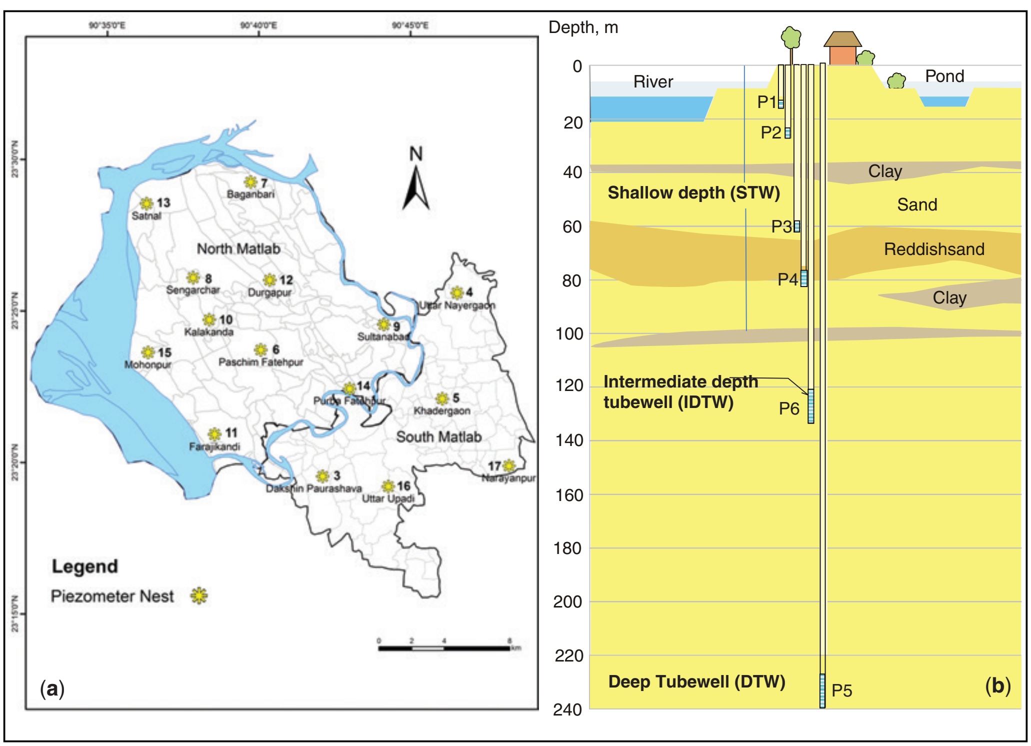

Figure 8.4 Design for the assessment of hydrogeological suitability through installation of multi-level piezometer nests in Matlab, Bangladesh targeting the shallow, intermediate deep and deep aquifers.

The sediment color tool was developed through a iterative process, based on (i) the observations on the physical characterization of the sediment samples and their color during the installation of the piezometer nests up to a depth of 100 m, and (ii) a long term monitoring of the water quality in the different piezometer nest wells. From extensive field-trials in the study area, it was realised that local drilers can drill down to a depth of 100 m by hand-percussion (sludger) method. This situation is true for many other places in the country. In addition to the installed piezometers, some other drinking water wells were also monitored for which the color of sediments at the screen positions were known.

Groundwater samples were collected from 144 wells screened at depths with known sediment color during the period between 2009 and 2011 covering both pre- and post-monsoon seasons, and analysed in the laboratory for detailed water chemistry for major ions and trace elements including arsenic.

In terms of depth and As concentration, wide range of variability was observed for the black sediments, however 50% of wells ($n = 33$) in black sediments at very shallow depth (10–40 m) revealed average As concentration of 239 μg/L which is manifold above the Bangladesh drinking water standard and WHO guideline (Table 8.1). In the context of probability of As-enrichment in water abstracted from black-colored sediments, it is apparent that these are 'high-risk' sediments and recommended to avoid installation of tubewells in black sediments. On the contrary, groundwater from wells installed in shallow, red color sediments found within a depth ranging from 47 to 82 m ($n = 39$) had As concentration lower than the Bangladesh drinking water standard of 50 μg/L. Average and median values of As collected from the wells installed in the red sediments were below the WHO guideline value of 10 μg/L. Water collected from 25 wells installed in off-white sediments also show a quite similar pattern in terms of depth and As concentration. The white sediments seemed of less importance for installation of tubewells at shallow depths.

Table 8.1 Statistical summary of As concentration in groundwaters derived from the sediments of four broad color groups.

Color of Aquifer Sediment	Number of Wells	Depth Range (m)	Number of Samples Analyzed	Compliance with BDWS (%)	Compliance with WHO Guideline (%)	Max (μg/L)	Min (μg/L)	Mean (μg/L)	Median (μg/L)
Black	66	9–91	230	17	9	740.8	5.6	239.2	240.1
White	14	58–104	49	71	21	150.6	5.6	36.1	27.7
Off-white	25	24–88	119	88	60	43.9	2.6	12.1	8.4
Red	39	47–82	123	100	62	21.8	2.6	9.4	8.6

(Unpublished SASMIT database, Hossain *et al.* 2014).

Groundwaters abstracted from black sediments have Ca-Mg-HCO_3 to Na-Cl-HCO_3 as dominant water types, while it is predominantly Na-Cl-HCO_3 type in case of white and red sediments (Figure 8.5). Abundance of Ca and Mg was also observed in waters derived from off-white sediments. Groundwater abstracted from the black sediments had high concentration of HCO_3^-, DOC, Fe^{2+}, NH_4^+ and PO_4, concomitant with low Mn and SO_4^{2-} content. In contrast, in waters from wells screened in red and off-white sediments, Mn and SO_4^{2-} concentrations were high with corresponding low levels of HCO_3^-, DOC, Fe^{2+}, NH_4^+ and PO_4. However, the levels of Mn in wells in both red and off-white sediments, were higher than the previous WHO guideline value of 0.4 mg/L (Table 8.2). In the revised guideline, WHO (WHO, 2011) has withdrawn the regulatory limit for Mn, on the premises that Mn concentrations in drinking water sources worldwide are well below the health based guideline value of 400 μg/L and hence there is a need for re-evaluating the guideline value of Mn in drinking water (Ljung & Vahter, 2007). Although, the levels of Mn in groundwater in the Bengal Basin is in general a matter of concern, it is a crucial determinant for advocating the exploitation of red and/or off-white sand aquifers for installation of shallow tubewells from the perspectives of Water Safety Plan (WHO, 2004).

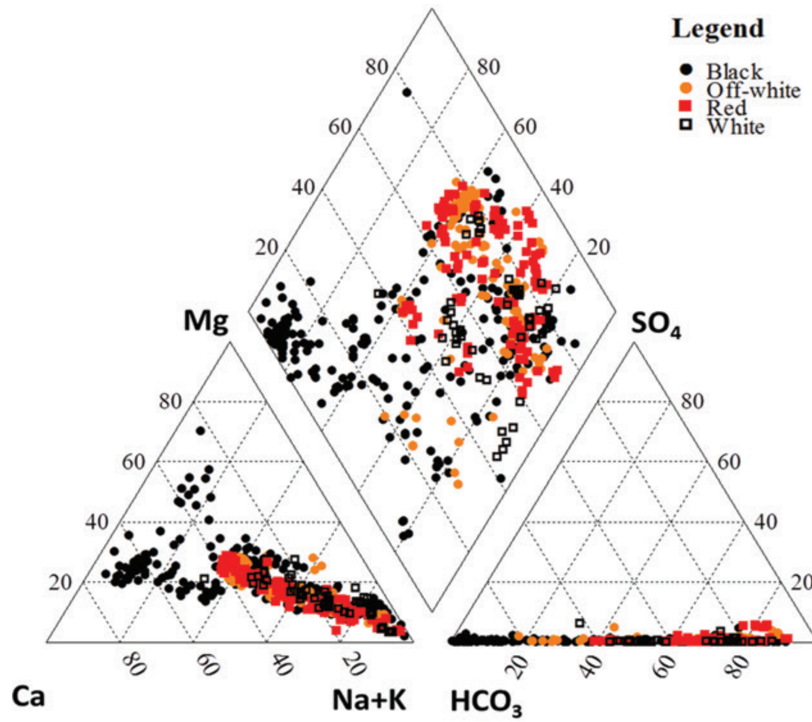

Figure 8.5 Major ion composition of groundwater derived from the four distinct sediment color groups plotted on a Piper diagram. (SASMIT Database, Hossain *et al.* 2014.)

From all the 15 locations, 2240 sediment samples were collected up to a depth of 100 m and characterized on the basis of their color and grain size. For assigning color of the sediments, and then to categorize them into four colors as perceived and practised by the local drillers, the following three steps method (Hossain *et al.* 2014) was used to develop the sediment color tool (Figure 8.6):

Step-1: Immediately after collection of sediment sample, each of them was described based on the visual inspection in the moist condition and this color has been recorded as 'field observed color'.

Step-2: Each sample was then compared with the Munsell Color Chart and using this chart Munsell Color and Munsell Code were recorded respectively. These two steps (1 and 2) eventually led to finding all possible color varieties.

Step-3: In the narrow down process, each sample was finally assigned to one of the four colors – black, white, off-white and red (Figure 8.3). These four colors are the driller's perception of sediment color which they have gained through their work experience. During the assignment of four colors, participatory approach was considered with utmost importance taking the opinions of local drillers, field geologists and technical experts into account.

Table 8.2 Statistical summary of redox sensitive elements in groundwaters from four broad color groups of aquifer sediments.

Sediment Color	Black			White			Off-White			Red		
No. of wells	66			14			25			39		
Number of groundwater samples monitored	230			49			119			123		
Redox Parameters	**Max**	**Min**	**Mean**	**Max**	**Min**	**Mean**	**Max**	**Min**	**Mean**	**Max**	**Min**	**Mean**
Mn (mg/L)	4.0	0.01	0.7	2.1	0.01	0.5	4.3	0.01	2.0	4.8	0.2	2.0
Fe (mg/L)	40.3	0.01	6.5	30.9	0.8	7.1	10.8	0.1	2.0	18.9	0.01	1.7
SO_4 (mg/L)	39.3	0.01	1.9	20.7	0.01	1.4	54.4	0.01	3.9	72.9	0.01	5.7
HCO_3 (mg/L)	1052	122	454	465	84	276	641	87	227	648	61	222
DOC (mg/L)	29.6	1.4	9.6	11.5	1.3	4.8	9.8	0.3	3.5	10.3	0.6	4.5
NH_4-N (mg/L)	57.8	0.01	6.3	10.2	0.01	1.7	12.8	0.01	0.48	2.6	0.01	0.2
PO_4-P (mg/L)	11.5	0.01	1.7	4.7	0.01	1.1	3.7	0.01	0.3	0.8	0.01	0.1

(SASMIT Database, Hossain *et al.* 2014).

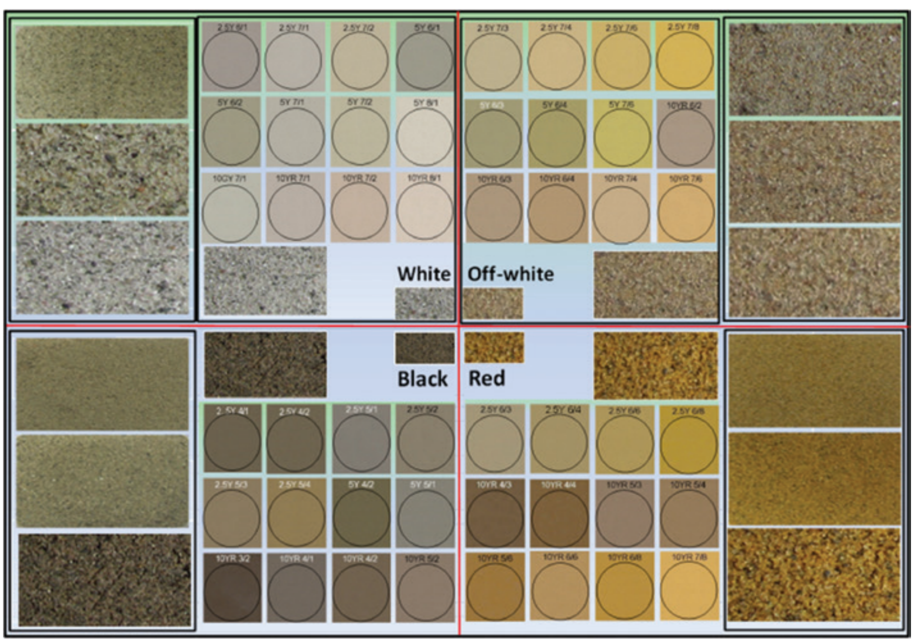

Figure 8.6 The color scheme based on the 4 color hypothesis with Munsell color and codes for the aquifer sediments recovered at shallow depths (<100 m). (Revised from SASMIT, 2014; Hossain *et al.* 2014.)

8.2.3.2 A simplified tool for the local drillers

The Sediment Color Tool has been further simplified to make it conveniently usable in the field by the local drillers and other stakeholders. In the process of simplification, all possible color shades under each of the four color groups were again categorized into light (1), moderate (2) and deep (3) shades to cover the entire range of the variability of the respective color (Figure 8.7).

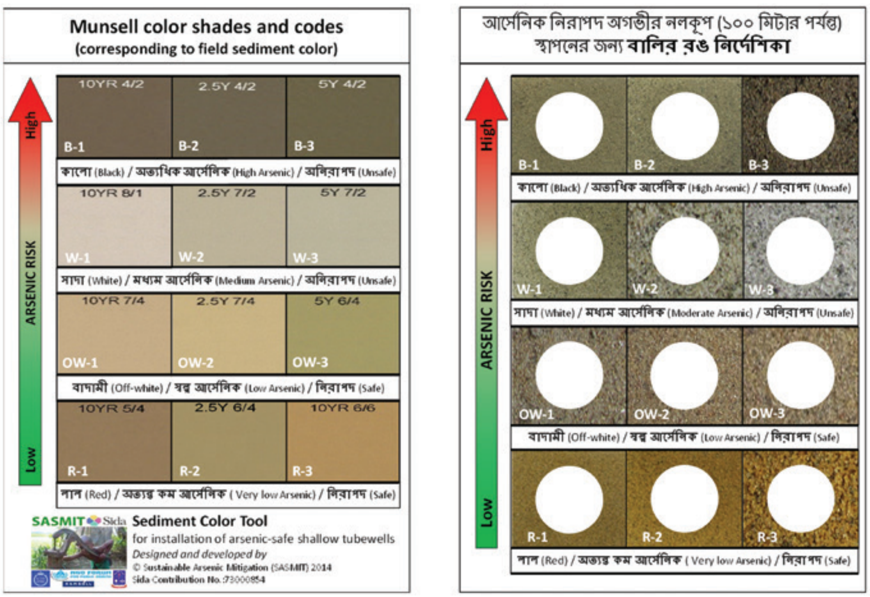

Figure 8.7 A simplified prototype of Sediment Color Tool for deployment in the field to be used by the local drillers and other stakeholders.

The local drillers would be able to use this simplified tool for making a decision on the appropriateness of the targeted sediments for the installations of shallow tubewells for drinking water supply.

8.2.3.3 Intermediate Deep Tubewells (IDTW) – Newly explored source of safe drinking water

Tubewells installed by the local drillers are the most widely used and socially accepted drinking water option in rural Bangladesh, which signifies the importance of identification of safe aquifers within a reasonable depth for scaling the safe water access in affected regions of Bangladesh. Depth of the tubewell is a key parameter in the context of groundwater quality and cost of tubewwell installation. In Bangladesh, a large proportion of the shallow wells (usually <80 m) are affected by arsenic contamination, and as a mitigation option, deep hand tubewells are installed usually to a depth range of about 250 m, which costs about 4–5 times of the installation cost of shallow tubewells. Compared to the demand for safe water tubewell, the number of deep wells is still very limited mainly because of the cost of installation, which is beyond the affordability of the poor and disadvantaged community of society (Bhattacharya *et al.* 2015).

The shallow aquifers characterized by sands of red and off-white color are the potential source of As-safe water, but elevated Mn is a concern for the compliance with the previous WHO limits for Mn and thereby the compliance with the Water Safety Plan (WHO, 2004). Considering the water quality data revealed from the groundwaters derived from red and off-white sediments, and based on field trials and water quality monitoring of piezometers, the SASMIT project made an attempt to find an option which could be suitable for compliance with the Water Safety Plan in the context of both As and Mn. Based on the hydrogeological investigation (hydrostratigraphy and hydrogeochemistry), a strategy was developed systematically, to explore the intermediate-deep aquifer for tapping As-safe and low manganese groundwater. This allowed the discovery of the groundwater resources between traditional shallow and deep aquifers for the installation of tubewells for the first time for drinking water supplies. These aquifers targeted at a depth of 120 m and below have been termed as intermediate deep aquifers (IDA) and the tubewells installed targeting these aquifers are termed as intermediate deep tubewells (IDTW) (Figure 8.4b). Detailed water chemistry results including As, Mn, major ions and other trace elements for 243 IDTWs installed in Matlab "provided promising results which support the strategy for exploitation of IDA as safe sources for installation of drinking water tubewells" (SASMIT 2014; Bhattacharya *et al.* 2014, 2015). Among 243 wells, only 3 wells exceeded the Bangladesh drinking water standard for As (50 µg/L) "and more than 91% ($n = 222$) were within the WHO guideline value of 10 µg/L. For Mn, 216 wells (89%) show concentration lower than the previous WHO guideline value of 0.4 mg/L" (SASMIT 2014; Bhattacharya *et al.* 2015; Hossain, 2015) (Figure 8.8).

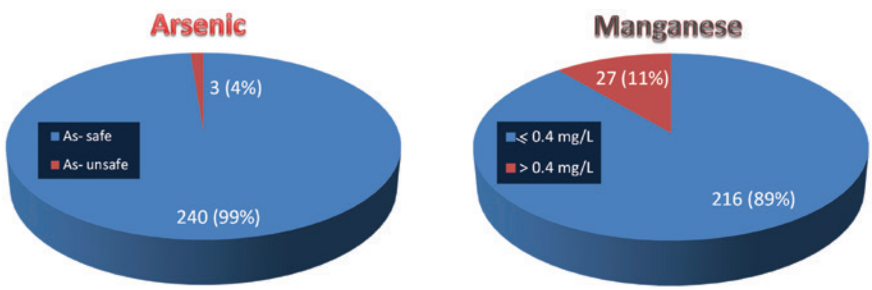

Figure 8.8 Arsenic-safe and low manganese well statistics for the Intermediate Deep Tubewells (IDTW) (referred from SASMIT 2014; Hossain, 2015).

Replication trials conducted in five upazilas, namely Gazaria, Bhedarganj, Shibchar, Palong and Muradnagar in south-central and south-eastern Bangladesh validated the wider applicability of the IDTW as an emerging source for drinking water supplies. The local drillers can target similar sand at this depth in range, the cost of installation per well could be reduced by 50% of the cost of deep tubewell installation. Thus IDTW is considered a novel innovation for promoting safe water access faster by the local community taking into account affordability (SASMIT 2014; Ahmed & Bhattacharya, 2014; Bhattacharya *et al.* 2014, 2015; Hossain, 2015).

8.2.4 Integration of technical and socio-economic aspects for optimisation of safe water access

The process of action research leading to the development of SASMIT strategy involving a novel combination of technical (hydrogeological suitability) and social aspects strengthened the initiative of the local tubewell drillers at the community level and local capacity building for arsenic mitigation. Based on the monitoring of water quality in the piezometer nests and considering safe buffer distances around these piezometer locations, clusters of villages (mauzas) were intervened for selection of sites for safe tubewell installation. Social mapping of all the villages within the targeted mauzas were carried out to make an assessment of the availability of safe water options for all clusters of households (baris) (SASMIT, 2014; Bhattacharya *et al*. 2014; Hossain, 2015). In optimization of site selection, priority was given to the baris with no or limited safe water access and poor and underserved households. The tubewells were installed considering the easy access to the site from all households within the respective cluster (Figure 8.9).

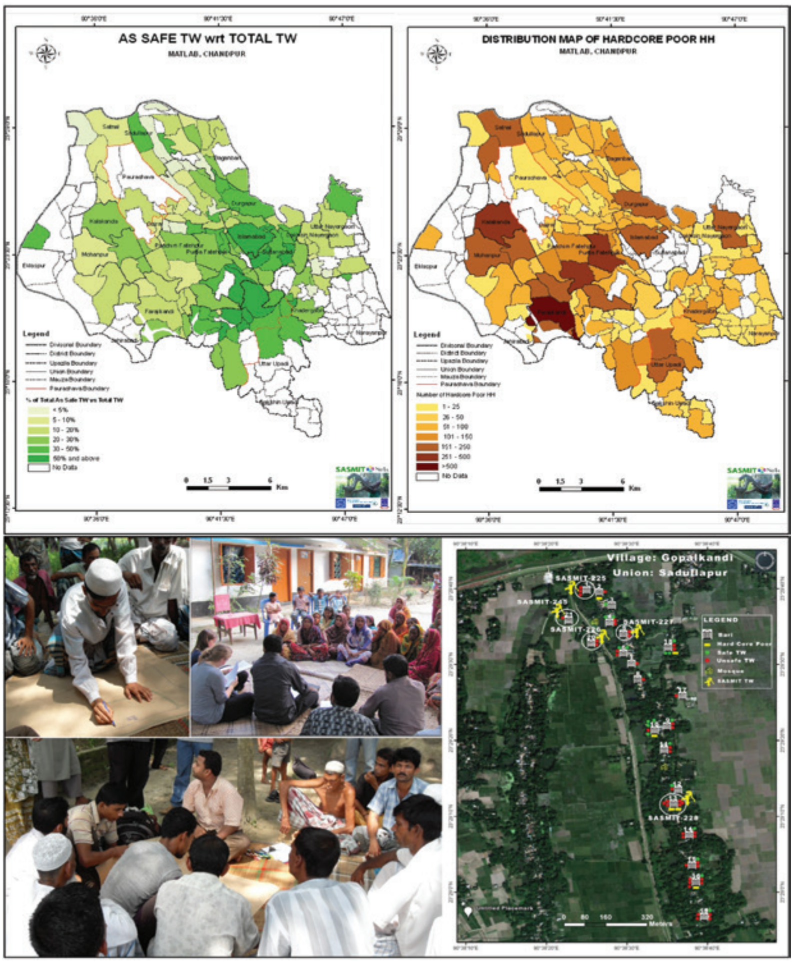

Figure 8.9 (Top) Existing safe water access and household economic status; (Bottom left) Village consultation meetings; and (Bottom right) cluster of households (baris) identified for tubewell installation during SASMIT implementation.

Adapting this strategy, 96% of the newly installed wells were safe with respect to As resulting in scaling up the safe water access from virtually non-existing to up to 40 percent (Figure 8.10). It is also important to mention that as compared to the outcomes of the action research on hydrogeological suitability and the demand for safe drinking water in Matlab, the resources for implementation could only cater improvement of the safe water access preferentially targeted in areas with poor to very poor access to safe water. The knowledge generated from the current SASMIT research has a potential for expanding the safe water access scenario through continuous implementation in the Matlab region making this a model as sustainable development solution (SDS) to achieve the Vision 2030 UN SDG (UN-SDSN, 2016).

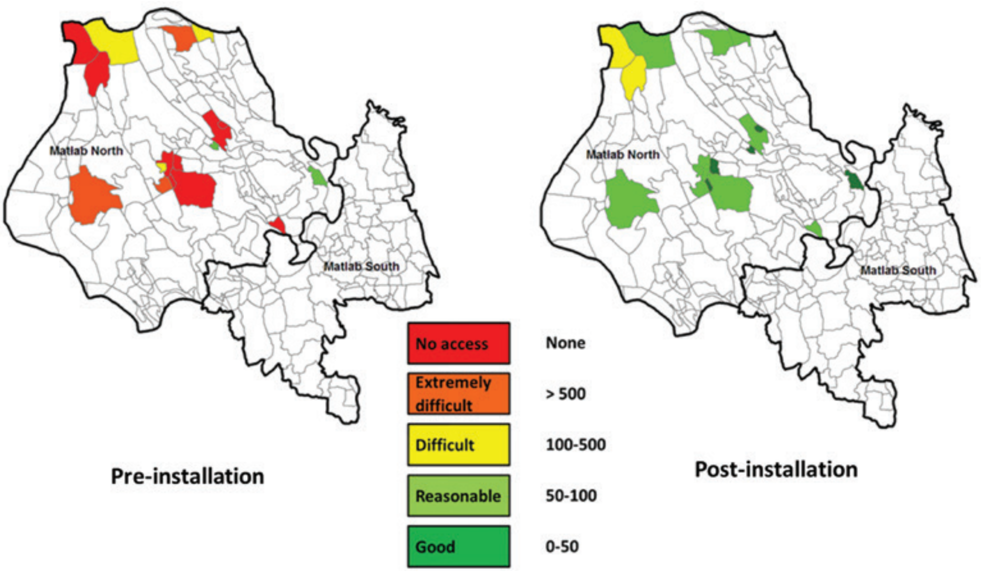

Figure 8.10 Improved safe water access in the Matlab area from the installed IDTW following the SASMIT methodology (Hossain, 2015).

8.2.5 Capacity building of the local drillers

The ever increasing dependence on groundwater in Bangladesh, for drinking water supplies especially in the rural areas, enhances the significance of the role of the local drillers, although widespread As contamination pose a challenge to them in tubewell installation. Local drillers are the main driving force for tubewell installation, and their perception on the nature of the sediments in terms of color, depth and water quality should be taken as a key consideration during implementation of drinking water supply projects. The close interaction and mutual sharing of knowledge and experience between the local drillers and the project team will contribute to optimize the sites for installation of safe tubewells. Involvement of the drillers in the context of capacity building would also help to develop entrepreneurship, in addition to enhancing awareness and knowledge for targeting safe aquifers, and thereby to reduce the exposure to As contamination on a country-wide scale.

8.3 COMPLIANCE WITH THE POLICY REGIME OF SUSTAINABLE ARSENIC MITIGATION IN BANGLADESH

Lack of adequate integration of evidence-based research results and the societal aspects, previous efforts of arsenic mitigation could not bring any visible change in the scenario of scaling-up safe drinking water access for millions of population exposed to the risk of chronic arsenic poisoning. Among the three major challenges for Bangladesh rural water supply, outlined in the Sector Development Plan (FY, 2011–2025) for the Water and Sanitation Sector (Policy Support Unit (PSU, 2011), arsenic has been identified as the priority contaminant due to its adverse health outcomes.

The Sida-SASMIT concept (SASMIT, 2014) offers a unique example for improvement of the safe drinking water access through:

- Providing safe and affordable access to water for the remaining areas in the country where risks of arsenic exposure is high
- Red sand aquifers could be a low-cost option which would minimize the exposure of arsenic
- Intermediate deep aquifers (IDA) could be a feasible option for tackling both arsenic and manganese. Approximately at half of the cost needed for DTW, the IDTWs affordable by the communities would be helpful to enhance the safe water coverage faster
- Wider applicability of SASMIT strategy through mapping of intermediate deep aquifers as safe water source as the action research component of SASMIT during the future implementation process with other sector organizations at a country wide scale
- Incorporate relevant social aspects for implementation of tubewell installation considering the demand and ensuring resource optimization to maximize the number of beneficiaries
- The recognition of the role of the local tubewell drillers as the driving force in tubewell installation is important to regulate the abstraction of water through different wells according to the recently ratified Bangladesh Water Act (2013).

The Sida-SASMIT project implementation has adequately addressed the necessity of the development of the capacity of the local drillers to identify the safe aquifers for installing drinking water wells. This will also form a strong base for their professional development to enabling them to participate and lead the way to work in collaboration within the local institutions and participate in decision making process for installing a new tubewell for the end users.

8.4 CONCLUSIONS AND FUTURE OUTLOOK

The SASMIT strategy developed through a combination of hydrogeological suitability and social aspects can improve the safe water access in arsenic affected areas (Bhattacharya *et al.* 2014; SASMIT 2014). It also helps ensuring the capacity building of the local drillers for identification of safe aquifers for the installation of safe drinking water tubewells. installation. Social mapping has been used as an important tool for optimization of sites for ensuring easy access to new safe well installations for a greater number of beneficiaries. Such mapping would be also useful as a reference for the evaluation of the improvement of safe water access from future implementations (Bhattacharya *et al.* 2014; SASMIT 2014).

The Sediment color tool developed on the basis of perception of the sediment color by the local driller's and monitoring of water quality is recommended to target safe aquifers for the provision of arsenic-safe drinking water. SASMIT has also discovered intermediate deep aquifers (IDA) for the installation of intermediate deep tubewells (IDTW) producing As-safe and low-Mn water for compliance to the Water Safety Plan (Bhattacharya *et al.* 2014; SASMIT 2014). Sustainability of the mitigation option needs to be assessed through long term water quality monitoring as prioritized in the Sector Development Plan (2011–2025) for Bangladesh. Collaboration of the Strategic National Partners with the Sida-SASMIT project consortium would facilitate the process of up-scaling the safe water access in the country.

Wider applicability of SASMIT strategy is envisaged for arsenic mitigation in Bangladesh and across the globe in areas with similar hydrogeological environments. Based on the methods developed by SASMIT, implementation of safe well installation carried out in Matlab, has been very much successful and promising. In addition to the up-scaling of safe water access, this method involved local drillers that ultimately led to their capacity building for entrepreneurship as well as to convey the message (awareness) to the community at large. For validation, replication trials have already been successfully made in some other areas with limited scope and resources.

SASMIT strategy has been shared through Policy and Strategy Documents, and Best Practices Manual with policy makers and sector agencies towards improvement of safe water access. This strategy allows installing safe wells based on (1) limited hydrogeological investigation to ensure the optimum rate of success and sustainability; and (2) implementation plan using GIS based simple and quick social mapping to ensure relatively uniform distribution to optimize the safe water access with respect to the number of installations.

However, there will always be needs for further monitoring and surveillance and the development of database with open access to see the changes in the improvement of safe water access, complementing the scenario of potential risks of As contamination and the sustainability of arsenic-safe drinking water supplies. Groundwater management is an important determinant for the success, as the proliferation of irrigation wells may impact regional and/or local level hydraulics in the context of cross-contamination. In long-run, it emphasizes the local driller's education and to bring them under a regulatory framework which will make them more responsible to target safe water sources during tubewell installation practice. Therefore, without further delay in involving further research, it is important to accelerate the mitigation efforts using present knowledge and the developed SASMIT strategy.

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8.6 REFERENCES

Ahmed K. M. and Bhattacharya P. (2014). Groundwater arsenic mitigation in Bangladesh: Two decades of advancements in scientific research and policy instruments. In: One Century of the Discovery of Arsenicosis in Latin America (1914–2014) As 2014, M. I. Litter, H. B. Nicolli, M. Meichtry, N. Quici, J. Bundschuh, P. Bhattacharya and R. Naidu (eds), Interdisciplinary Book Series: *"Arsenic in the Environment – Proceedings"*. Series Editors: J. Bundschuh and P. Bhattacharya, CRC Press/Taylor and Francis (ISBN 978-1-138-00141-1), pp. 886–888.

Ahmed K. M., Bhattacharya P., Hasan M. A., Akhter S. H., Alam S. M. M., Bhuyian M. A. H., Imam M. B., Khan A. A. and Sracek O. (2004). Arsenic contamination in groundwater of alluvial aquifers in Bangladesh: An overview. *Applied Geochemistry*, **19**(2), 181–200.

Ahmed M. F., Ahuja S., Alauddin M., Hug S. J., Lloyd J. R., Pfaff A., Pichler T., Saltikov C., Stute M. and van Geen A. (2006). Epidemiology – ensuring safe drinking water in Bangladesh. *Science*, **314**, 1687–1688.

Argos M., Kalra T., Rathouz P. J., Chen Y., Pierce B., Parvez F., Islam T. T., Ahmed A., Rakibuz-Zaman M., Hasan R., Sarwar G., Slavkovich V., van Geen A., Graziano J. and Ahsan H. (2010). Arsenic exposure from drinking water, and all-cause and chronic-disease mortalities in Bangladesh (HEALS): a prospective cohort study. *Lancet*, **376**(9737), 252–258.

AsMat Report (2007). Arsenic in Tube Well Water and Health Consequences, Sida Final Report, Dhaka, Bangladesh.

BBS/UNICEF (Bangladesh Bureau of Statistics/United Nations Children's Fund). (2011). Bangladesh National Drinking Water Quality Survey of 2009. UNICEF, Dhaka, Bangladesh, 192p.

BDWS (1997). The Environmental Conservation Rules (Schedule-3), Ministry of Environment and Forest, Government of the Peoples Republic of Bangladesh, Dhaka, Bangladesh.

BGS-DPHE (2001). Arsenic contamination of groundwater in Bangladesh. In: D. G. Kinniburgh and P. L. Smedley (eds), Final Report. BGS Tech. Rep. WC/00/19, British Geological Survey; Keyworth, UK, 267 pp.

Bhattacharya P., Chatterjee D. and Jacks G. (1997). Occurrence of arsenic-contaminated groundwater in alluvial aquifers from Delta Plains, eastern India: options for safe drinking water supply. *International Journal of Water Resources Development*, **13**(1), 79–92.

Bhattacharya P., Jacks G., Jana J., Sracek A., Gustafsson J. P. and Chatterjee D. (2001). Geochemistry of the Holocene Alluvial sediments of Bengal Delta Plain from West Bengal, India: Implications on arsenic contamination in groundwater. In: Groundwater Arsenic Contamination in the Bengal Delta Plain of Bangladesh, G. Jacks, P. Bhattacharya and A. A. Khan (eds), KTH Special Publication, TRITA-AMI Report 3084, pp. 21–40.

Bhattacharya P., Frisbie S. H., Smith E., Naidu R., Jacks G. and Sarkar B. (2002a). Arsenic in the Environment: A Global Perspective. In: Handbook of Heavy Metals in the Environment, B. Sarkar (ed.), Marcell Dekker Inc., New York, pp. 147–215.

Bhattacharya P., Jacks G., Ahmed K. M., Khan A. A. and Routh J. (2002b). Arsenic in Groundwater of the Bengal Delta Plain Aquifers in Bangladesh. *Bulletin of Environmental Contamination and Toxicology*, **69**(4), 538–545.

Bhattacharya P., Hossain M., Jacks G., Ahmed K. M., Hasan M. A. and von Bromssen M. (2014). Groundwater arsenic pollution: A conceptual framework for sustainable mitigation strategy. In: One Century of the Discovery of Arsenicosis in Latin America (1914–2014) As 2014, M. I. Litter, H. B. Nicolli, M. Meichtry, N. Quici, J. Bundschuh, P. Bhattacharya and R. Naidu (eds), Interdisciplinary Book Series: "*Arsenic in the Environment – Proceedings*". Series Editors: J. Bundschuh and P. Bhattacharya, CRC Press/Taylor and Francis (ISBN 978-1-138-00141-1), pp. 881–885.

Bhattacharya P., Hossain M., Hasan M. A., Ahmed K. M., von Bromssen M. and Jacks G. (2015). Hydrogeochemical Characterization of Shallow, Intermediate and Deep Aquifers in Matlab, Bangladesh – Implications for the Installation of Arsenic-Safe Drinking Water Tubewells and their Sustainability. Geological Society of America Annual Meeting, Baltimore, USA, 1–4 November 2015, Paper No. 334-7.

Bhattacharya P., Hossain Jacks G., Ahmed K. A., Hasan M. A., von Brömssen M. and Frape S. K. (2016). Hydrogeochemical contrasts across the multi-level aquifers of Bengal basin in Matlab, Bangladesh: Implications for arsenic free and low-manganese drinking water sources. In: Arsenic Research and Global Sustainability As 2016, P. Bhattacharya, M. Vahter, J. Jarsjö, J. Kumpiene, C. Sparrenbom, G. Jacks, M. E. Donselaar, J. Bundschuh and R. Naidu (eds), Interdisciplinary Book Series: *"Arsenic in the Environment – Proceedings"*. Series Editors: J. Bundschuh and P. Bhattacharya, CRC Press/Taylor and Francis (ISBN 978-1-138-02941-5), pp. 45–46.

Biswas A., Nath B., Bhattacharya P., Halder D., Kundu A. K., Mandal U., Mukherjee A., Chatterjee D., Mörth C.-M. and Jacks G. (2012). Hydrogeochemical contrast between brown and grey sand aquifers in shallow depth of Bengal Basin: consequences for sustainable drinking water supply. *Science of the Total Environment*, **431**, 402–412.

Bundschuh J., Litter M. and Bhattacharya P. (2010). Targeting arsenic-safe aquifers for drinking water supplies. *Environmental Geochemistry & Health*, **32**, 307–315.

Chakraborty M., Mukherjee A. and Ahmed K. M. (2015). A review of groundwater arsenic in the Bengal Basin, Bangladesh and India: from source to sink. *Current Pollution Reports*, **1**, 220–247.

Chowdhury A. M. R. and Jakariya M. (1999). Testing of water for arsenic in Bangladesh. *Science*, **284**(5420), 1621–1621.

Datta S., Neal A. W., Mohajerin T. J., Ocheltree T., Rosenheim B. E., White C. D. and Johannesson K. (2011). Perennial ponds are not an important source of water or dissolved organic matter to groundwaters with high arsenic concentrations in West Bengal, India. *Geophysical Research Letters*, **38**, L20404. http://dx.doi.org/10.1029/2011GL049301.

Guha Mazumder D. N., Haque R., Ghosh N., De B. K., Santra A., Chakraborti D. and Smith A. H. (2000). Arsenic in drinking water and the prevalence of respiratory effects in West Bengal, India. *International Journal of Epidemiology*, **29**, 1047–1052.

Harvey C. F., Swartz C. H., Badruzzaman A. B. M., Keon-Blute N., Yu W., Ali M. A., Jay J., Beckie R., Niedan V., Brabander D., Oates P. M., Ashfaque K. N., Islam S., Hemond H. F. and Ahmed M. F. (2002). Arsenic mobility and ground-water extraction in Bangladesh. *Science*, **298**, 1602–1606.

Harvey C. F., Ashfaque K. N., Yu W., Badruzzaman A. B. M., Ali M. A., Oates P. M., Michael H. A., Neumann R. B., Beckie R., Islam S. and Ahmed M. F. (2006). Groundwater dynamics and arsenic contamination in Bangladesh. *Chemical Geology*, **228**, 112–136.

Hasan M. A., Ahmed K. M., Sracek O., Bhattacharya P., von Brömssen M., Broms S., Fogelström J., Mazumder M. L. and Jacks G. (2007). Arsenic in shallow groundwater of Bangladesh: investigations from three different physiographic settings. *Hydrogeology Journal*, **15**, 1507–1522.

Hossain M. (2015). Sustainable Arsenic Mitigation: A Strategy Developed for Scaling-Up Safe Water Access. PhD thesis. KTH Royal Institute of Technology. ISBN 978-91-7595-789-0.

Hossain M., Bhattacharya P., Ahmed K. M., Hasan M. A., von Brömssen M., Islam M. M., Jacks G., Rahman M. M., Rahman M., Rashid S. M. A. (2010). Sustainable Arsenic Mitigation (SASMIT): an approach for developing a color based tool for targeting arsenic-safe aquifers for drinking water supply. In: Metals and Related Substances in Drinking Water Cost Action 637, P. Bhattacharya, I. Rosborg, A. Sandhi, C. Hayes and M. J. Benoliel (eds), *Proceedings of the 4th International Conference, METEAU*, Kristianstad, Sweden, IWA Publishing, London, UK, pp. 272–276.

Hossain M., Bhattacharya P., Frape S. K., Jacks G., Islam M. M., Rahman M. M., von Brömssen M., Hasan M. A. and Ahmed K. M. (2014). Sediment color tool for targeting arsenic-safe aquifers for the installation of shallow drinking water tubewells. *Science of the Total Environment*, **493**, 615–625.

Hossain M., Rahman S. N., Bhattacharya P., Jacks G., Saha R., Rahman M. (2015). Sustainability of arsenic mitigation interventions – an evaluation of different alternative safe drinking water options provided in Matlab, an arsenic hot spot in Bangladesh. *Frontiers in Environmental Science*, **3**(30), 1–15. doi: 10.3389/fenvs.2015.00030

Hug S. J., Gaertner D., Roberts L. C., Schirmer M., Ruettimann T., Rosenberg T. M., Badruzzaman A. B. M. and Ali M. A. (2011). Avoiding high concentrations of arsenic, manganese and salinity in deep tubewells in Munshiganj District, Bangladesh. *Applied Geochemistry*, **26**(7), 1077–1085.

Hoque B. A., Hoque M. M., Ahmed T., Islam S., Azad A. K., Ali N., Hossain M. and Hossain M. S. (2004). Demandbased water options for arsenic mitigation: An experience from rural Bangladesh. *Public Health*, **118**, 70–77.

Inauen J., Hossain M. M., Johnston R. B. and Mosler H. J. (2013). Acceptance and use of eight arsenic safedrinking water options in Bangladesh. *PLoS One*, **8**(1), e53640. http://dx.doi.org/10.1371/journal.pone.005360.

Islam F. S., Gault A. G., Boothman C., Polya D. A., Charnock J. M., Chatterjee D. and Lloyd J. R. (2004). Role of metal-reducing bacteria in arsenic release from Bengal delta sediments. *Nature*, **430**, 68–71.

Jakariya M., Chowdhury A. M. R., Hossain Z., Rahman M., Sarker Q., Khan R. I. and Rahman M. (2003). Sustainable community-based safe water options to mitigate the Bangladesh arsenic catastrophe – An experience from two upazilas. *Current Science*, **85**(2), 141–146.

Jakariya M., Rahman M., Chowdhury A. M. R., Rahman M., Yunus M., Bhiuya M. A., Wahed M. A., Bhattacharya P., Jacks G., Vahter M. and Persson L.-Å. (2005). Sustainable safe water options in Bangladesh: experiences from the Arsenic Project at Matlab (As-Mat). In: Natural Arsenic in Groundwater: Occurrence, Remediation and Management, J. Bundschuh, P. Bhattacharya, and D. Chandrasekharam (eds), Balkema, London, pp. 319–330.

Jakariya M., von Brömssen M., Jacks G., Chowdhury A. M. R., Ahmed K. M. and Bhattacharya P. (2007). Searching for sustainable arsenic mitigation strategy in Bangladesh: experience from two upazilas. *International Journal of Environment and Pollution*, **31**(3/4), 415–430.

Jakariya M., Vahter M., Rahman M., Wahed M. A., Hore S. K., Bhattacharya P., Jacks G. and Persson L.-Å. (2007). Screening of arsenic in tubewell water with field test kits: Evaluation of the method from public health perspective. *Science of the Total Environment*, **379**, 167–75.

Jonsson L. and Lundell L. (2004). Targeting safe aquifers in regions with arsenic-rich groundwaters in Bangladesh. Case study in Matlab Upazila, Minor Field Studies, vol. 277. Swedish University of Agricultural Sciences, Uppsala, Sweden.

Kabir A. and Howard G. (2007). Sustainability of arsenic mitigation in Bangladesh: Results of a functionality survey. *International Journal of Environmental Health Research*, **17**, 207–218.

Kapaj S., Peterson H., Liber K. and Bhattacharya P. (2006). Human health effects from chronic arsenic poisoning – A review. *Journal of Environmental Science and Health, Part A,* **41**(10), 2399–2428.

Ljung K. and Vahter M. (2007). Time to re-evaluate the guideline for manganese in drinking water? *Environmental Health Perspectives*, **115**(11), 1533–1538.

Mukherjee A., Bhattacharya P., Savage K., Foster A. and Bundschuh J. (2008). Distribution of geogenic arsenic in hydrologic systems: controls and challenges. *Journal of Contaminant Hydrology*, **99**(1–4), 1–7.

Mukherjee A., von Brömssen M., Scanlon B. R., Bhattacharya P., Fryar A. E., Hasan M. A., Ahmed K. M., Chatterjee D., Jacks G. and Sracek O. (2008). Hydrogeochemical comparison between the Bhagirathi and Meghna sub-basins, Bengal basin, India and Bangladesh: effects of overlapped redox zones on dissolved arsenic. *Journal of Contaminant Hydrology*, **99**(1–4), 31–48.

Mukherjee A. B. and Bhattacharya P. (2001). Arsenic in groundwater in the Bengal Delta Plain: Slow Poisoning in Bangladesh. *Environmental Reviews*, **9**, 189–220.

Munsell Color x-rite (2009). Munsell Soil-Color Charts with Genuine Munsell Color Chips. Munsell Color, MI, USA. Revised, 2009.

McArthur J. M., Banerjee D. M., Hudson-Edwards K. A., Mishra R., Purohit R., Ravenscroft P., Cronin A., Howarth R. J., Chatterjee A., Talukder T., Lowry D., Houghton S., Chadha D. (2004). Natural organic matter in sedimentary basins and its relation to arsenic in anoxic groundwater: the example of West Bengal and its worldwide implications. *Applied Geochemistry*, **19**, 1255–1293.

Nickson R., McArthur J., Burgess W., Ahmed K. M., Ravenscroft P. and Rahman M. (1998). Arsenic poisoning of Bangladesh groundwater. *Nature*, **395**, 338.

Nriagu J. O., Bhattacharya P., Mukherjee A. B., Bundschuh J., Zevenhoven R. and Loeppert R. H. (2007). Arsenic in soil and groundwater: an overview. In: Arsenic in Soil and Groundwater Environment: Biogeochemical Interactions, Health Effects and Remediation, P. Bhattacharya, A. B. Mukherjee, J. Bundschuh, R. Zevenhoven and R. H. Loeppert (eds), Trace Metals and other Contaminants in the Environment, Volume 9, Elsevier B. V., Amsterdam, The Netherlands, pp. 3–60. (DOI: 10.1016/S0927-5215(06)09001-1).

Pal T. and Mukherjee P. K. (2008). 'Orange sand' – a geological solution for arsenic pollution in Bengaldelta. *Current Science*, **94**(1), 31–33.

Pal T. and Mukherjee P. K. (2009). Study of subsurface geology in locating arsenic-free groundwater in Bengal delta, West Bengal, India. *Environmental Geology*, **56**(6), 1211–1225.

Polizzotto M. L., Kocar B. D., Benner S. G., Sampson M. and Fendorf S. (2008). Near-surface wetland sediments as a source of arsenic release to ground water in Asia. *Nature*, **454**, 505–509.

Polya D. and Charlet L. (2009). Rising arsenic risk? *Nature Geoscience*, **2**, 383–384.

Polya D. A. and Lawson M. (2015). *Geogenic and Anthropogenic Arsenic Hazard in Groundwaters and Soils – Disitribution, Nature, Origin and Human Exposure Routes*. In: Arsenic: Exposure Sources, Health Risks and Mechanisms of Toxicity, States J. Christopher (ed.), John Wiley and Sons, DOI: 10.1002/9781118876992.ch2

Parvez F., Chen Y., Yunus M., Olopade C., Segers S., Slavkovich V., Argos M., Hasan R., Ahmed A., Islam T., Akter M. M., Graziano J. H. and Ahsan H. (2013). Arsenic Ex-posure and Impaired Lung Function: Findings from a Large Population-based Prospective Cohort Study. *American Journal of Respiratory and Critical Care,* **188**(7), 813–819.

Parvez F., Slavkovich V., Graziano J. H., Chen Y., Wu F., Olopade C., Argos M., Ahsan H., Yunus M., Hasan R., Ahmed A., Islam T. and Sarvar G. (2016). Arsenic exposure, non-malignant respiratory outcomes and immune modulation in the health effects of arsenic longitudinal study (HEALS) cohort. In: Arsenic Research and Global Sustainability As 2016, P. Bhattacharya, M. Vahter, J. Jarsjö, J. Kumpiene, C. Sparrenbom, G. Jacks, M. E. Donselaar, J. Bundschuh and R. Naidu (eds), Interdisciplinary Book Series: *"Arsenic in the Environment – Proceedings"*. Series Editors: J. Bundschuh and P. Bhattacharya, CRC Press/Taylor and Francis (ISBN 978-1-138-02941-5).

Policy Support Unit (PSU). (2011). Sector Development Plan (FY 2011–2025), Water and Sanitation Sector in Bangladesh. Local Government Division, Ministry of Local Government, Rural Development and Cooperatives, Government of the People's Republic of Bangladesh. See http://www.psu-wss.org/assets/book/sdpeng.pdf

Rahman M. M., Naidu R. and Bhattacharya P. (2009). Arsenic contamination in groundwater in the Southeast Asia region. *Environmental Geochemistry & Health*, **31**, 9–21.

Robinson C., von Brömssen M., Bhattacharya P., Häller S., Bivén A., Hossain M., Jacks G., Ahmed K. M., Hasan M. A. and Thunvik R. (2011). Dynamics of arsenic adsorption in the targeted arsenic-safe aquifers in Matlab, South-eastern Bangladesh: insight from experimental studies. *Applied Geochemistry*, **26**(4), 624–635.

SASMIT (2014). Sustainable Arsenic Mitigation (SASMIT), Community Driven Initiatives to Target Arsenic Safe Groundwater as Sustainable Mitigation Strategy (Sida Contribution No.:73000854) – Concept Note. KTH International Groundwater Arsenic Research Group, Department of Sustainable Development, Environmental Science and Engineering, KTH Royal Institute of Technology, Stockholm, Sweden. See http://dx.doi.org/10.13140/2.1.1290.3200

Saunders J. A., Lee M. K., Uddin A., Mohammad S., Wilkin R., Fayek M. and Korte N. (2005). Natural arsenic contamination of Holocene alluvial aquifers by linked tectonic, weathering, and microbial processes. *Geochemistry Geophysics Geosystems*, **6**, Q04006.

Smith A. H., Lingas E. O. and Rahman M. (2000). Contamination of drinking water by arsenic in Bangladesh: a public health emergency. *Bulletin of the World Health Organization*, **78**, 1093–1103.

Smith A. H. and Steinmaus C. M. (2009). Health effects of arsenic and chromium in drinking water: Recent human findings. *Annual Review of Public Health*, **30**, 107–122.

Stollenwerk K. G., Breit G. N., Welch A. H., Yount J. C., Whitney J. W. and Forster A. L. (2007). Arsenic attenuation by oxidized sediments in Bangladesh. *Science of the Total Environment*, **379**, 133–150.

UN-SDSN (2016). Getting Started with SDG Implementation. UN Sustainable Development Solutions Network – A Global Initiative for the United Nations. See http://unsdsn.org/what-we-do/sustainable-development-goals/getting-started-with-sdg-implementation/

van Geen A., Ahasan 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., Slakovich V., Lolacono N. J., Becker M., Cheng Z., Momtaz H., Shahnewaz M., Seddique A. A. and Graziano J. (2002). Promotion of well-switching to mitigate the current arsenic crisis in Bangladesh. *Bulletin of the World Health Organization*, **80**, 732–737.

van Geen A., Ahmed K. M., Seddique A. A. and Shamsudduha M. (2003). Community wells to mitigate the current arsenic crisis in Bangladesh. *Bulletin of the World Health Organization*, **82**, 632–638.

von Brömssen M. Bhattacharya P., Ahmed K. M., Jakariya M., Jonsson L., Lundell L. and Jacks G. (2005). Targeting safe aquifers in regions with elevated arsenic in groundwater of Matlab Upazila, Bangladesh. In: Book of Abstracts, E. Lombi, S. Tyrell, A. Nolan, M. McLaughlin, G. Pierzynski, M. Gerzabek, N. Lepp, C. Leyval, M. Selim, F. Zhao, C. Grant and D. Parker (eds), *8th International Conference on the Biogeochemistry of Trace Elements*, Adelaide, Australia, pp. 190–191.

von Brömssen M., Jakariya M., Bhattacharya P., Ahmed K. M., Hasan M. A., Sracek O., Jonsson L., Lundell L. and Jacks G. (2007). Targeting low-arsenic aquifers in groundwater of Matlab Upazila, Southeastern Bangladesh. *Science of the Total Environment*, **379**, 121–132.

von Brömssen M., Larsson S. H., Bhattacharya P., Hasan M. A., Ahmed K. M., Jakariya M., Sikder A. M., Sracek O., Bivén A., Doušová B., Patriarca C., Thunvik R. and Jacks G. (2008). Geochemical characterisation of shallow aquifer sediments of Matlab Upazila, Southeastern Bangladesh – implications for targeting low-As aquifers. *Journal of Contaminant Hydrology*, **99**(1–4), 137–149.

WHO (2004). Guidelines for Drinking-Water Quality, 3rd edn, World Health Organization, Geneva, 515p.

WHO (2006). Guidelines for Drinking-Water Quality. First Addendum to Third Edition, Volume 1 Recommendations. World Health Organization, Geneva, 515p.

WHO (2011). Guidelines for Drinking-Water Quality, 4th edn, World Health Organization, Geneva, 541p.

World Bank (1970). East Pakistan – Tubewells Project. In: *Agriculture projects Series* PA 49. World Bank, Washington, DC. 119p. See http://documents.worldbank.org/curated/en/1970/06/722538/east-pakistan-tubewells-project (accessed 20 July 2016).

Yu C. and Ahsan H. (2004). Cancer burden from arsenic in drinking water in Bangladesh. *American Journal of Public Health*, **94**, 741–744.

Zheng Y., Stute M., van Geen A., Gavrieli I., Dhar R., Simpson H. J., Schlosser P. and Ahmed K. M. (2004). Redox control of arsenic mobilization in Bangladesh groundwater. *Applied Geochemistry*, **19**(2), 201–214.