Bangladeshi arsenic- and salt-mitigation sourcebook and decision-support tool

Final report

In partial fulfilment of the ASTRA-Bangladesh project (BRAC WASH II program)

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COLOPHON

This document was prepared in the project **‘A**iding **S**ustainable Water **T**echnology **R**ealization in **A**rsenic contaminated Areas of Bangladesh’ or for short ‘*ASTRA-Bangladesh*’ in the framework of the *BRAC WASH II* program (http://www.irc.nl/brac). This program is managed by *BRAC* and *IRC* International Water and Sanitation Centre and funded by the *Embassy of the Kingdom of the Netherlands* (Bangladesh).

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IRC Supporting water sanitation and hygiene services for life

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SUMMARY

This publication contains the detailed description of the ASTRA arsenic- and salt-mitigation tool developed in the framework of the BRAC WASH II programme. In essence, this work is a supporting compendium and tool for decision-makers, practictioners and education institutes. It's main objective is to aim understanding and identification of potentially appropriate technological solutions to tackle the widespread arsenic and salinitiy problems in the water sources of Bangladesh. Confirm the currently available solutions, the work leans towards the removing or mitigating of arsenic and – where treatments are included – solutions that mainly concern disinfection and (in)filtration. The contained information draws on both Bangladeshi and international research and practical experience.

The general mitigation strategy is explained as the identification of potentially appropriate water supply methods for implementation in Bangladesh. The identification process is based on a multidisciplinary assessment and matching of method functionality with the intended local context. This book contains both the critical reviews and practical information of all potentially applicable technical mitigation methods to aid decision-makers and engineers.

In the first chapter of the publication, the growing water stress and its key drivers in Bangladesh are listed and detailed. This sourcebook section enables the proper understanding of mitigation methods through a range of critical reviews that can either treat or circumvent arsenic- or salt-contaminated sources. Three mitigation routes are outlined that include water supply or treatment methods. These mitigation options are to (i) target arsenic- or salt-free groundwater, (ii) treat arsenic- or salt-contaminated groundwater or (iii) disinfection of alternative, non-groundwater sources.

Utilizing one or more of the identified mechanisms, 26 specific technological methods are identified as eligible for the Bangladeshi water sector context. Their in-depth descriptions are given in chapter 6 of this book. The descriptions of technical, institutional, ecological and socio-economic features are completed by eligibility matrices. The matrices demonstrate quality of functioning according to local- or project-specific criteria and allow users to assess performance of the method in the context of application.

The description of the content of the decision-suport tool are coupled to the manual on how to use it and the related online version. Finally, a discussion is offered that tackles indirect considerations that Bangladeshi water experts could apply to further improve the sustainability of the local water sector.

The chosen structure of this publication allows two distinctively different utilizations. Decision-makers and engineers may view potential approaches first before formulating specific strategies to mitigate the arsenic-related problems. As the compendium section is also possible to use without the more theoretical initial parts, especially field experts are hoped to benefit from the technology information sheets and matrices during multistakeholder processes of water projects.

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1 Introduction

1.1 Rationale of arsenic- and salt-mitigation in Bangladesh

1.1.1 Challenges in Bangladeshi water supply

Bangladesh faces a growing water crisis. Being one of the most densely populated countries in the world, it has over 150 million inhabitants living on 147,570 km^2. About 6.4 % of its total area is covered by water, which increases the average population density to 1020 inhabitants per km^{-2} (UNSTATS, 2013). The high population density is combined with a very low average income level. Poverty indicators estimate that 43.3 % of the population earns less than USD1.25 pppd and as much as 57.8% suffers from multidimensional poverty (UNDP, 2013). The widespread poverty prompts that water supply is sub-optimal for most of the country's low-income population.

Bangladesh is characterized by extreme hydrological features resulting in frequent flood events. The annual precipitation of 2666 mm (national average) ranges between 1,200-5,000(!) mm regionally. As most of this precipitation falls in the monsoon season it is the key contributor to large-scale flooding each year (World Bank, 2014; Chowdhury, 2010). The yield of the Ganges-Brahmaputra-Meghna river system that delivers 93% of the surface water into Bangladesh exhibits a 25:1 ratio in peak to low flow between the seasons. As a result of these extremes, Bangladesh faces water abundance with severe floods in the summer and water scarcity in the October-March period each year. On average, it is estimated that areas flooded annually may reach 37 % of the total land surface. In 1998, the highest flood coverage recorded in Bangladeshi history has submerged two-third of the country (FAO-AQUASTAT, 2013).

Besides the regular droughts, diverse contaminations increase water stress in Bangladesh. Pathogenic contamination of surface and shallow groundwaters is a key contributor to the limited availability of safe water in the country. Van Geen et al. (2011) has shown that 19-64% of the surveyed shallow wells were prone to high contamination during all but the driest months of the year. Waterborne diseases related to pathogenic contamination are key drivers in WASH-related deaths in Bangladesh. In 2004, still 8.5% of all deaths in the country were linked in some way to this water (and sanitation) problem (FAO-AQUASTAT, 2013).

In addition to the pathogenic challenge, the growing saline intrusion in the coastal areas and the widespread arsenic (As) contamination of the country's shallow aquifers contribute to the drastic reduction of available safe water sources in Bangladesh.

1.1.2 Overview of the arsenic- and salt-mitigation challenge

In the recent past, the increasing population pressure and the related environmental load resulted in a growing contamination of the surface water streams. The continued use of these water sources led to frequent epidemics that shifted focus to alternative water sources (Field *et al.*, 2011). Since the '80s, about 8.6 million hand-pumps were installed in primarily large-scale development aid programs (Petrusevski *et al.*, 2007). These initiatives focused their efforts on utilizing pathogen-free, shallow groundwater aquifers. With the dissemination of hand-pumps, Bangladesh took a major step towards nationwide access to microbially safe drinking water. At present, still about 79 % of all drinking water is estimated to be withdrawn from diverse groundwater sources (FAO-AQUASTAT, 2013).

In 1993, naturally occurring arsenic was discovered in the groundwater (Caldwell *et al.*, 2003; Crow and Sultana, 2002; Kinniburgh and Smedley, 2001). Chronic exposure to arsenic poses a serious risk to human health as it results in pathogenic reactions in the form of skin, lungs, urinary bladder and kidney cancer (WHO, 2006; Smith *et al.*, 2002). Today, the extent of exposure to dangerous concentrations of arsenic in drinking water is estimated to affect 25-45 million Bangladeshi inhabitants (based on exposure levels of >50 µg L^{-1} and >10 µg L^{-1}, respectively). An annual death rate of 43,000 is associated with this disaster and the rural poor is identified as the most vulnerable group in the Bangladeshi society (Flanagan *et al.*, 2012). The damage caused by the consumption of arsenic-contaminated water is not only health related; the economic loss resulting from the reduced working hours of the sick is estimated at USD 13 billion for the coming twenty years (Flanagan *et al.*, 2012).

Arsenic-mitigation is shown to be an unavoidable challenge in (Bangladeshi) water management chains. The removal of this contaminant is very complex, as its safe removal depends on the presence of other contaminants (iron, manganese) and because it may require extensive treatment including adsorbents, membrane filtration or chemical dosage. As a result, strongly decentralized mitigation strategies had high failure rates in the past. The required time and cost to properly operate and maintain HWTS (household water treatment and safe storage) technologies proved often beyond the capacity of the households involved. Reports also confirmed that the low rate of proper HWTS application was related to the underestimation of the associated risk. As arsenic-contaminated water is frequently free of significant turbidity and smell, many users tend to accept it as clean.

Saline intrusion is another growing problem, mainly manifesting in the coastal areas of Bangladesh. This phenomenon does not only affect drinking water sources, but irrigation as well. With that, it will not only affect the water sector, but also the food sovereignty in the region. The increasing salinity is primarily induced by climate change with (i) the increase in sea level, (ii) the strongly reduced rainfall in the dry season and (iii) extreme weather events (e.g. cyclones). In addition, human activities related to water abstraction and upstream management of the largest rivers also contribute to the shrinking of the safe water base in the Bangladeshi coast (Khan *et al.*, 2011).

At present, attempts to reduce risk of arsenic- and salt-contamination make use of a small range of technological methods. Deep-tube wells and rainwater harvesting technologies are the most frequently used safe water options in this regard. Deep wells enjoy widespread popularity because at depths in excess of 80m most aquifers are free of significant contaminations. Rainwater use is widespread as it is a renewable source of (largely) contaminant-free water. Unfortunately, both systems have significant bottlenecks that limit their use. Deep-tube well applicability depends strongly on local geology and the occurrence of manganese contamination. In addition, the cost of this option and the sometimes considerable fetching distance may constraint their rate of utilization by the rural poor (Inauen *et al.*, 2013). The potential of rainwater harvesting methods are indicated to have low acceptance rates. Similarly to HWTS devices, this is motivated by the fact that rainwater methods require considerable efforts from the users both during the implementation and the application phases.

So far, technological implementations were only partly successful in abating arsenic- and salt-contamination problems in Bangladesh. In order to increase resilience of current mitigation methods and ensure the proper implementation of new ones, this study outlines a novel arsenic- and salt-mitigation strategy that focuses on the identification of appropriate water methods for diverse Bangladeshi implementation contexts.

1.2 Development of the ASTRA arsenic- and salt-mitigation strategy

1.2.1 The BRAC WASH II programme

The BRAC WASH I programme (2006-2011) was initiated to improve access of the Bangladeshi rural poor to water, sanitation and hygiene-related services. The entire programme reached almost 38.8 million people with hygiene promotion. Improved sanitation was implemented for a population of 25.6 million, while 1.78 million gained access to new or improved water facilities (IRC/BRAC, 2012).

Following the completion of the BRAC WASH I programme in 2011 (IRC/BRAC, 2012), the BRAC WASH II programme was started in 2012 with the objective to further improve WASH sectors in Bangladesh:

> *'… to contribute to the attainment of the Millennium Development Goals by providing integrated water services, sanitation and hygiene promotion expanding to hard-to-reach areas and to under-served populations, in collaboration with government and other stakeholders, while continuing to reinforce gains made in the original WASH I areas'*

As part of the BRAC WASH II programme, one of the six tendered subjects (the ASTRA project) concentrates on the research and evaluation of low-cost, appropriate water supply technologies for the mitigation of arsenic- and salt-problems. The current study details the results of this research, teremed the ASTRA project (**A**iding **S**ustainable Water **T**echnology **R**ealization in **A**rsenic and Salinity contaminated Areas of Bangladesh).

1.2.2 The ASTRA project

The ASTRA arsenic- and salt-mitigation approach incorporates a sourcebook and a decision-support tool. The sourcebook contains fundamental descipitions and critical reviews on relevant water supply and treatment methods. The ASTRA tool is a decision-support instrument that contains multidisciplinary, practical descriptions of water technologies and their functional ranges in so-called eligibility matrices. The decision aid in the ASTRA tool consists of offering method relevance information in diverse project contexts. This type of mitigation approach has its origin in earlier offline works, such as the sourcebook and decision aid for the Philippines (WSP-Worldbank, 2005) or the EAWAG sanitation compendium (Tilley *et al.*, 2008) (see section 2.1 for details). Similarly to the approach of these examples, the ASTRA approach and the included tool are designed to offer comprehensive information to describe potentially applicable arsenic- and salt-mitigation methods and highlight key issues for proper functioning. It also aims to offer decision-support by defining proper applicability and limitations of the included water supply or treatment methods.

The information in this sourcebook and decision aid covers all main disciplines necessary for a resilient water sector:

- **financial/economic** information on different costing, financing and affordability issues including capital and O&M costs where possible and further key economic challenges and opportunities for project developers;
- **institutional** framework information including legal and policy matters;

- **ecological** information including hydro-geological and other catchment issues;
- **technological** information covering main installation and O&M considerations, field performance;
- **social and hygiene** information on social acceptance and the necessity of awareness raising or behaviour change campaigns; and
- **management** information highlighting the activities and strategies to ensure sustainable operation of a facility or device.

The fundamental desciptions in this sourcebook aim at the basic understanding of mitigation approaches. They offer background information on the practical compendium and their primarily theoretical descriptions offer a knowledge platform that is resistent to changes in water sector development. For example, the aplicability of chemical oxidation or evaporation may alter over time, but the described theory offers a relatively constant knowledge base to count on. The section on the mitigation strategy (chapter 2) and the three fundamental chapters (chapters 3-5) are expected to benefit developers of actual mitigation strategies locally or regionally and potentially knowledge institutes that are involved in the training of such experts.

The practical compendium section (chapter 6) embodies the more concrete side of the decision support aid. The information included represents the state-of-the-art in arsenic- and salt-mitigation at the time of writing. It is important to note that the included specific information section (e.g. purchase costs and fees) is more vulnerable to new developments in water treatment and supply. With the contained information, this integrated compendium aims to support policy-makers, engineers and even less professional stakeholder groups (i.e. beneficiaries or donors) to identify appropriate water technologies according to financial, environmental, institutional, technological, social, economic and management aspects.

1.2.3 Methodology

The research for this tool focused on the acquisition, analysis and synthesis of information regarding water methods applied in arsenic- and salt-mitigation in Bangladesh. The data acquisition considered three main sources, namely (i) academic publications (monographs, reports and papers), (ii) (practical) water supply/treatment project reports and other output and (iii) interviews with Bangladeshi and international water experts. Information was often scarce on method performance during large-scale field surveys, so the approached experts were interviewed in open-ended discussions to offer their view (Annex 1). Their responses and information are integrated into the Technology Information Sheets (TIS) and the related eligibility matrices (section 7). Cross-checking of obtained information allowed for a critical review on existing and potential future mitigation options.

The scope of analyzed methods contains

i. best practice technologies involved in arsenic- and salt-mitigation in the Bangladeshi-context,
ii. sustainable technologies for arsenic- and salt-removal in the international, development-context,
iii. high-tech technologies potentially relevant for Bangladeshi arsenic- and salt-mitigation, and
iv. promising arsenic- and salt-removal methods in development; potentially relevant for Bangladesh in the foreseeable future.

The selected methods are described and evaluated in a standardized framework. Classified per discipline and practical use, they aid the comparison and quick understanding of method potential without time-consuming research into the whole subject or method.

1.3 Structure of the book

The introduction chapter described the growing water stress from arsenic- and salinity-problems in Bangladesh. As a response to this challenge, a comprehensive sourcebook and decision aid is offered in this publication.

Chapter 2 describes the general mitigation strategy that involves how multidisciplinary eligibility is defined and viewed against the context-related aspects. The main routes for mitigation are outlined and the structuring and working of the decision-support tool are given. Finally, this section also includes information on intended users, optimal application and key limitations.

In Chapters 3-5, the fundamentals and Bangladeshi relevance of the potential mitigation mechanisms in water supply and treatment are described. These chapters aim at providing in-depth information on operational fundamentals, required material streams (e.g. reagents) and quality of removal or supply. Preceding each of these descriptions, the code(s) of the relevant technical method(s) are listed to enable optimal coupling of the theory to the practical solutions (chapter 6).

In chapter 6, the complete content of the decision-support tool is given. This content comprises a multidisciplinary description of each method (through the so-called technology information sheets) and the related performance assessment matrices to guide users on the optimal application and the boundaries for each method in the Bangladeshi context.

Chapter 7 contains a discussion of indirect traits that should help the proper selection of water methods. In this chapter, sector-wide financial and institutional considerations are included such as novel financing approaches and the diversification of water resources. A closing section (chapter 8) contains the final remarks and recommendations. The conclusions section includes highlights on both the research process and key importance of the final sourcebook. The recommendations sub-section offers the most important considerations for the future use of the ASTRA tool.

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2 Description of the general mitigation strategy

2.1 The ASTRA approach

2.1.1 Brief historical overview of sourcebooks and decision-support tools

The implementation and use of appropriate methods is a key prerequisite in achieving an improved water sector. Technology selection is relatively easy in wealthy, developed countries where the dominantly centralized water supply creates a high level of uniformity. In these sectors, technology selection is straight-forward because the small number of choices are simplified through regulations and engineering standards. Maintenance of existing systems is made efficient, as the uniformity ensures that most parts are interchangeable and easy to obtain. This infrastructural, technical and institutional grid is limited in most developing countries. Even where a standardized water supply method does exist (e.g. a central water treatment and supply chain), it is often vulnerable to limitations in infrastructure, part supply and obtaining skilled labor. As a result, strongly infrastructure dependant, high-tech solutions are largely omitted and their application is limited to the middle- and high-income communities in larger cities.

Diverse, primarily low-tech methods form the dominant group of solutions in most developing countries. These are designed to fit specific, asset-poor contexts, making it important to understand their optimal functioning for efficient implementation. In the past, the installation of improper water methods often resulted in failures or strongly sub-optimal functioning (SOURCE). The limited availability of local knowledge on the functionality of specific methods is stressed by the development of a growing number of compendia and similar works of knowledge in the WASH (water, sanitation and hygiene) sectors (Table 1).

Based on the available literature, knowledge dissemination in international WASH development shows a clear trend towards more multidisciplinarity and more interaction with the information user. From the 1980's onward, technological compendia were released by various organizations and authors. Starting from the publication of the Kalbermatten compendium, these books mainly focused on descriptive texts detailing the construction and applicability of best practice technologies for water and sanitation management (Table 1). In recent years, information provision on WASH methods took on an increasingly multidisciplinary orientation. To enable a rapid and in-depth understanding of the technologies and also their optimal embedding, a logical development was to highlight not only direct technological information but to also offer multidisciplinary knowledge regarding the contained technologies (e.g. the SSWM or Akvopedia portals). Another development of these compendia or tools is the involvement of a decision-support or decision-making feature. Such tools are characterized by offering multiple information types at more levels to provide tool users with easy-to-access information (including media sources) and a reliable decision-support. Proof to such a compendia and tools include the EAWAG compendium (Tilley *et al.*, 2008) or the online WaterCompass (PRACTICA *et al.*, 2013).

Table 1 Compendia focusing on affordable and appropriate drinking water supply methods

Resource	Content
Kalbermatten *et al.*,1980	Technical and economic summary of water and sanitation options
Brikké and Bredero, 2003	Compendium of water and sanitation technologies
Holden and Swanepoel, 2004	Compendium of water and sanitation technologies
Murcott, 2006	Household level water treatment and storage guide
Tilley *et al.*, 2008	Sanitation system compendium
NWP, 2009	Water technology compendium covering the whole water supply chain
NWP, 2010	Smart disinfection solutions, primarily for HWTS
PRACTICA *et al.*, 2013	WaterCompass - multidisciplinary decision decision-support tool for rapid drinking water method selection
AKVOPEDIA, 2011	Internet portal with water technologies covering the whole supply chain
RWSN, 2011	Technology descriptions on rural water supply
RAIN, 2011	Detailed rainwater harvesting decision-support tool with design parameter calculations
WASTE *et al.*, 2011	Integrated sanitation decision support tool
Bouman *et al.*, 2011	School sanitation decision-support tool document with detailed evaluation structure
Olschewski *et al.*, 2012	WASHTech tool - detailed assessment of water, sanitation and hygiene technologies
SSWM, 2012	Sanitation and water management compendium and toolbox

Source: Szántó *et al.*, 2012.

The ASTRA approach can also be seen as part of this development where mitigation strategy is understood as the collection and analysis of multidisciplinary method information in order to allow an objective screening for applicability.

2.1.2 Description of the mitigation approach

The ASTRA approach (Figure 1) involves an eligibility screening of 'best available technologies' for the selection of resilient water supply and treatment solutions in the Bangladeshi context.

The first step of this approach (section 2.2) involves the strategic analysis of the project or policy context for which one or more potential methods need to be identified. Extent of this assessment may vary depending on the specific goal of the method identification. In general, a few known traits of a project location or region may already be sufficient for the starting of the procedure. For a systematic context analysis, 21 factors were identified. These factors belong to three groups that define the natural, human and technical context in which the water method will need to function. Natural context factors (section 2.2.1) are included as they determine the (largely) unalterable traits of the given situation. Human factors (section 2.2.2) may be alterable (e.g. with behavior change campaigns), but any change is likely to require considerable efforts and time. In general, technical factors (section 2.2.3) offer the most flexible traits of the project context. Determining as many as possible of the 21 factors forms the first stage (i.e., context assessment) of the ASTRA approach.

The second stage of the procedure is the viewing of the potential water supply and treatment method groups to identify one or more approaches that may be applicable. 26 source development, conveyance and treatment methods were grouped according to three mitigation approaches. These approaches are described in section 2.3. Critical reviews of the included methods are listed in chapters 3-5. In each sub-chapter, the method principle and its technical proponent(s) are accompanied by the latest experimental developments that may be of use in the near future in Bangladesh. in t should be noted that these chapters also include a number of methods that are potentially applicable in specific contexts only or that are at present in an experimental stage, but show promise for use in Bangladesh. Depending on his preference, a tool user may opt for

1. Arsenic- and salinity-free groundwater abstraction (section 2.3.2);
2. Treatment of arsenic- or salt-containing groundwater (section 2.3.3); and
3. Appropriate, non-groundwater solutions incl. surface and rainwater options (section 2.3.4).

The ASTRA tool offers two uses. Users may either study the critical reviews on each of the included technologies for selection or make use of the practical 'technology information sheets' in Annex 1.

In the third stage (section 2.4), the technological methods are compared to the assessed situation from stage 1. To enable a simple & rapid decision-support, the functional range of all methods can be compared to the 21 factors and their options. Based on the user's choice for a specific option, it is easy to see whether the technological method is relevant for that specific project or policy setting. Once all methods are viewed for eligibility, the user can form a pool of potentially applicable methods. If this pool also contains only partially eligible methods, then factors of ineligibility need to be assessed as well. The final pool of methods can be used for the determination of the method of choice. This last selection phase should be optimally executed in a multistakeholder setting.

Once a method is selected and the planning phase of a project is executed, assessment of the actual tool implementation and functioning is advised. Monitoring and assessment of the intervention can be executed with several methods. This stage falls outside the scope of the ASTRA approach, but section 2.4.3 gives a brief overview of potential options. At the end of chapter 2, the different uses of the ASTRA sourcebook and decision-support tool are given together with a short analysis of the quality of this approach.

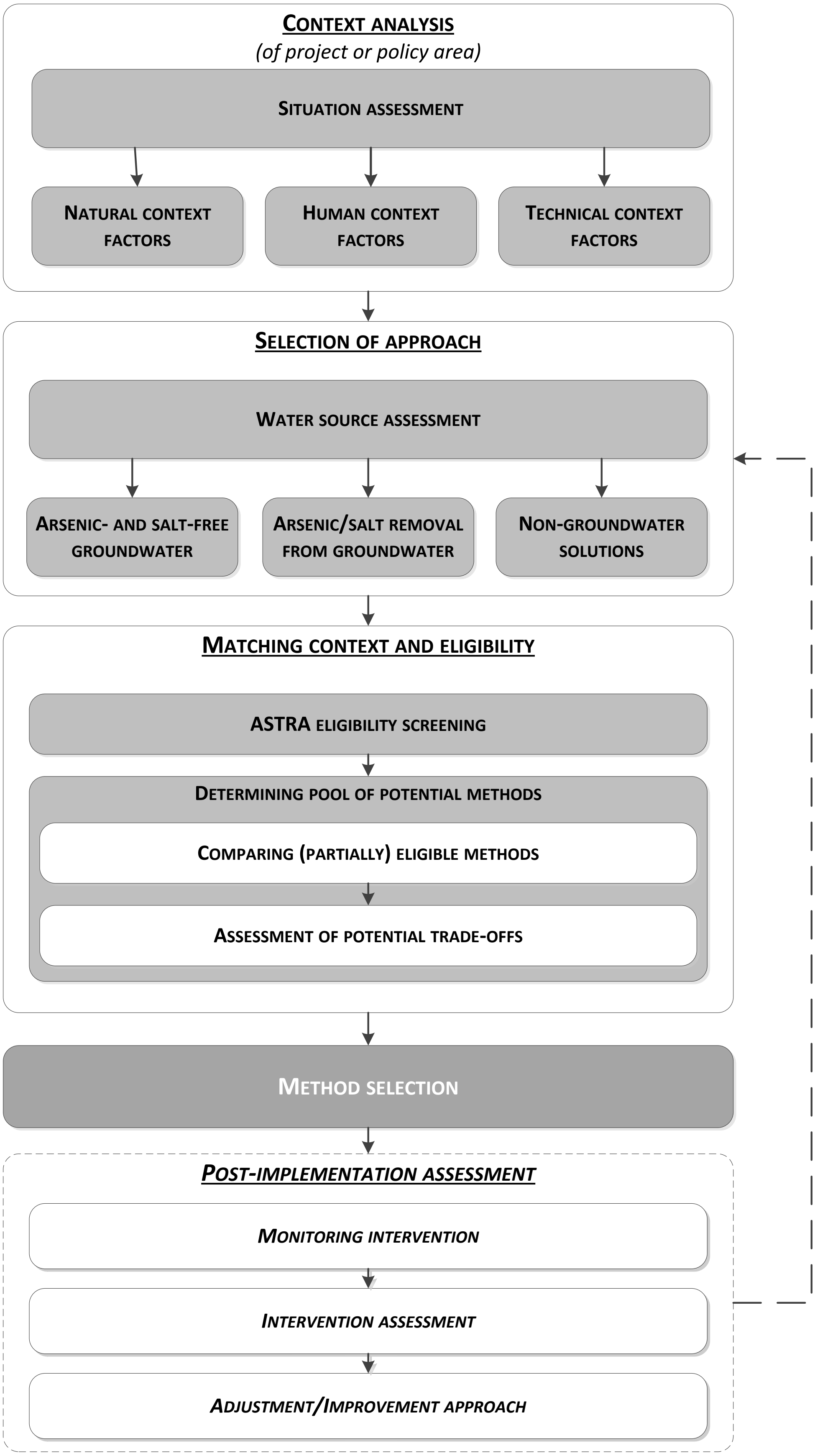

Figure 1 Structure and schematic presentation of the ASTRA approach

2.2 Context analysis

2.2.1 Introduction

Analysis of a project situation is a crucial first step in the determination of a proper response. Lack of a good understanding of the context in which a technological method is embedded may result in high failure rates and a repeated need for mitigation actions. There are numerous factors with differing importance that may describe a project context. An optimal tool reduces the complexity of analysis by limiting it to the analysis factors of the greatest importance. This is a challenging task, as it requires the identification of objective factors (perceived by everyone in the same way) and the assurance that the necessary information for those factors is likely to be available in most situations.

To offer an example, the level of willingness-to-pay is a crucial factor in assessing cost recovery and the rate of revenue. However, such information is often unavailable or hard to define without executing an extensive survey. For this reason, the ASTRA tool is designed to include natural-, human- and technological-context factors that are not only objective but are also identifiable in most situations. These factors were chosen after analysis of existing technology knowledge bases and decision-support tools. The proposed factors and their sub-categories were then cross-checked with water experts on quality. Only those factors that could support a meaningful classification remained in the tool. This implies that e.g. annual precipitation level was omitted because all Bangladeshi regions exhibit a relatively comparable profile. This makes rainwater harvesting methods similarly eligible (applicable in parts of the year) in each Bangladeshi region.

2.2.2 Natural context

Natural and environmental-context factors (Table 2) include those unchangeable aspects of an affected area that comprise the physical framework of technology implementation. All of these factors are related to natural issues as climate, geography or water catchment area. They include key aspects of the given water body such as type of source (rain, surface or groundwater) and its environmental or anthropogenic contaminations (arsenic, iron, bacteria or salt). It should be noted that contaminations not directly influencing arsenic- or salt-removal are excluded from the options. This has to do with the arsenic- and salt-mitigation focus of the ASTRA research. All contaminations that the included methods can treat are offered in both the critical reviews and the technology information sheets. Next to water quality, climate (flood risk, cyclones with storm surges) and hydro-geological (ground formation, water lifting) are included in the ASTRA tool.

Table 2 Natural context factors and their options in the ASTRA tool

Situation criteria	Included options	Signified aspect
Water source	Surface, brackish, rain- and groundwater	Locality of water body
Removal	Arsenic, salt	Arsenic or salt
Ground formation	Sand and gravel, clay formations, compacted formations, soft weathered rock and bedrock	Soil composition
Water lifting	0-8, 8-15, 15-40 and >40 m	Depth of water level
Flood danger	Not affected, only flooded in extreme weather & annually affected by floods	Level of flood risk

2.2.3 Human context

Human-context factors (Table 3) include socio-economic (level of delivery, scale of implementation), institutional (management level) and infrastructural (location, energy, access to site) aspects that are relevant for a water method selection. This group of factors is also characterized by being resilient to change. Like in case of the factor 'scale of implementation', an optimal level of dissemination may be altered but it would require great effort and a long period of time.

Table 3 Human context factors and their options in the ASTRA tool

Situation criteria	Included options	Signified aspect
Location	Densely populated urban; densely populated, low-income urban; moderately populated urban, peri-urban, rural and rural, remote	Settlement type and population density
Site selection	Settlement, agricultural and coastal	Type of location
Scale of implementation	Household, shared, small community, school or institution and large user group	Scale of sustainable dissemination
Preferred level of water delivery	Household, shared, small community, school or institution and large user group	Connection level to water supply
Preferred management level	Household, shared, small community, school or institution and large user group	Type and level of method managing
Energy available	None, electricity grid, fuel generated, solar and wind energy	Possible means of powering device
Access to site	On parcel, outside of household area, <10 minutes to access, <30 minutes to access and >30 minutes to access	Means of accessibility to water point

2.2.4 Technical context

Technical factors (Table 4) reflect on the technological (construction time, system sophistication) and economic (construction and maintenance costs) issues related to the deployment of a method. User acceptance is chosen to be included as a technology-dependent factor. This choice is justified if taken into account that acceptance of a method may be relatively quickly altered with awareness raising social methods. These aspects are flexible as they are more closely related to preferences in a project design than to the given situation. It is acknowledged that human or natural factors may co-determine technological preferences, but adjusting for example the preferred construction cost range is a choice of the tool user or project developer.

Table 4 Technical context factors and their options in the ASTRA tool

Situation criteria	Included options	Signified aspect
Status in Bangladesh	Widespread, known, little known and unknown	Level of embeddedness
System sophistication	Labor-intensive, intermediate and technology-intensive	Labor-using or automated process
Construction costs	Negligible, <USD25, USD25-100, USD100-1,000 and >USD1,000	Costs of physical installation
Maintenance costs	Negligible, <USD5 per month, USD5-100 per month and >USD100 per month	Costs related to O&M
Construction time	Insignificant, a day, several days to a week and weeks	Typical duration of constructing
Level of expertise in O&M	Household, local technician, local government and external experts	Required level of skills in O&M
User acceptance	No activity required, limited extension, considerable extension and extensive campaign required	Level of requirement to inform user about method (implementation)

2.3 Technical mitigation approaches

2.3.1 Assessment of potential approach

In stage 2 of the ASTRA approach a two-tiered compendium is offered to support the selection of the technical mitigation approach. The inventory (Figure 3) marks both the type of methods included with critical reviews in the following chapters and the practical technology information sheets. In practice, it is the technology information sheets that present the 'forefront' of the tool by allowing the formulation of the general approach and the critical reviews can aid this process by making information available in the fundamentals. With this approach, the ASTRA tool goes further than most of the knowledge bases in the past.

The technology inventory provides an overview of current and emerging technological interventions that can be implemented in arsenic mitigation strategies. The technologies are clustered in such a way that a safe water supply chain can be designed for a specific location. Figure 2 illustrates the three different technology categories and their placement between source and consumer: targeting arsenic- and salt-free groundwater, treatment of arsenic- and salt-contaminated groundwater and appropriate non-groundwater alternatives. It is noteworthy that the intervention with 'piped water supply schemes' are included within targeting arsenic-free water, whereas in reality it can also be combined with a water treatment. This illustrates that this technological inventory should not be interpreted as a summary of stand-alone technologies, as in many cases it is the smart combination of technologies in 'the source to mouth' chain that will result in sustainable and safe water supply.

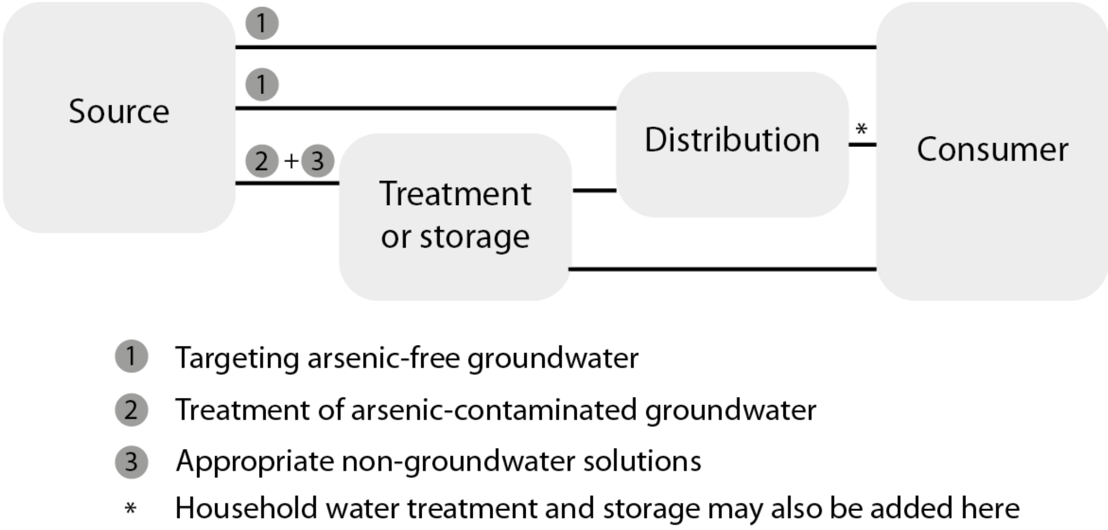

Figure 2 Schematic overview of arsenic mitigation strategies from source to consumer

The following sections in this chapter provide an explanation of each of the technology inventory categories. The individual technologies will be described in the literature review Chapters 3, 4 and 5. These chapters form the basis for the compilation of the Technology Information Sheets, which are part of the decision support tool. How different technologies can be combined is further discussed in Chapter 6.

2.3.2 Targeting arsenic- and salt-free groundwater

Groundwater is globally considered a very safe source for drinking water, as the deeper aquifers are protected against disease-causing microbial contaminants. With safe construction of bore holes, pumps and other abstraction infrastructure, the source is generally protected against human and animal pollution. Nevertheless, other – mostly inorganic – constituents may threaten the safety of this source of drinking water. Arsenic contamination has full attention in Bangladesh, as it can be found in aquifers in large parts of the country (BGS/DPHE, 2001). Since the installation of millions of household shallow tube wells (20-30m depth) the people of Bangladesh heavily rely on this source for their drinking water supply. More recently, also saline water intrusion in the coastal regions (Bahar and Reza, 2010) and elevated manganese concentrations in groundwaters (Hafeman *et al.*, 2007) are on the radar – making the safe water supply in this country an even more challenging task.

The combination of a high local variability of water source quality and decentralized organization structure requires an approach that takes into account these diverse local settings. The possibilities to target arsenic- and salt-free groundwater will depend greatly on the local geochemical- and hydrological conditions. The technological intervention methods can be subdivided into five categories:

- Deep tube wells (section 3.1)
- Dug wells (section 3.2)
- Shallow tube wells (section 3.3)
- Well sharing and switching (3.4)
- Small-scale, piped water networks (section 3.5)

METHOD INVENTORY

ARSENIC- AND SALT-FREE GROUNDWATER

- **Deep tube wells**
- **Dug well**
- **Shallow tube wells**
- **Well switching**
- **Piped water schemes**

ARSENIC/SALT REMOVAL FROM GROUNDWATER

- Oxidation of Arsenite
  - **Chemical Oxidation**
  - **Oxidation via Ultraviolet Radiation**
  - New Developments: Advanced Oxidation Technologies
- Precipitation, coagulation and filtration technologies
  - **Conventional coagulation and filtration**
  - **Lime Softening**
  - Household Water Treatment and Safe Storage Solutions
  - New Developments: Electrocoagulation
- Adsorption and ion exchange technologies
  - **Iron or Aluminium Oxides-Based Adsorbents**
  - **Zerovalent Iron (ZVI)**
  - Ion Exchange (IX) Resins
  - Household Water Treatment and Safe Storage Solutions
  - New Developments: Geological and Organic Adsorbents
- **Membrane-based technologies**
  - NF and Low-Pressure RO
  - Energy Recovery/Renewable Energy Powered Reverse Osmosis
  - New Membrane Developments
- Biological Processes
  - **Microbial-assisted arsenic removal technologies**
  - **Phytofiltration**
- In-Situ Remediation
  - **Permeable Reactive Barriers**
  - **Subsurface Arsenic Removal**

NON-GROUNDWATER SOLUTIONS

- **Rainwater harvesting and storage**
- **Evaporation technologies**
- **Infiltration galleries**
- Surface water treatment
  - **Pond sand filter**
  - Disinfection
    - **UV treatment**
    - **Chlorination**
  - Household Water Treatment and Safe Storage
    - Coagulation-flocculation
    - **Ceramic pot filter**
    - **Boiling**
- Natural engineered systems
  - **Riverbank filtration**
  - **Artificial and managed recharge**

Figure 3 Inventory of currently applied or potential future (technical) mitigation methods. Note: Methods of the ASTRA tool are given in bold.

The *deep tube well* (average depth >100m) is a safe water option in many regions of Bangladesh (Smedley and Kinniburgh, 2002), and according to a Worldbank/WSP household survey in rural communities (2003; see Figure 4) the 1st preferred arsenic mitigation option. Deep tube wells are generally applied for small communities or privately owned by richer households. The comparably low costs of shallow tube wells (20-30m depth), makes it also attractive to target arsenic- and salt-free *shallow or intermediate* water layers.

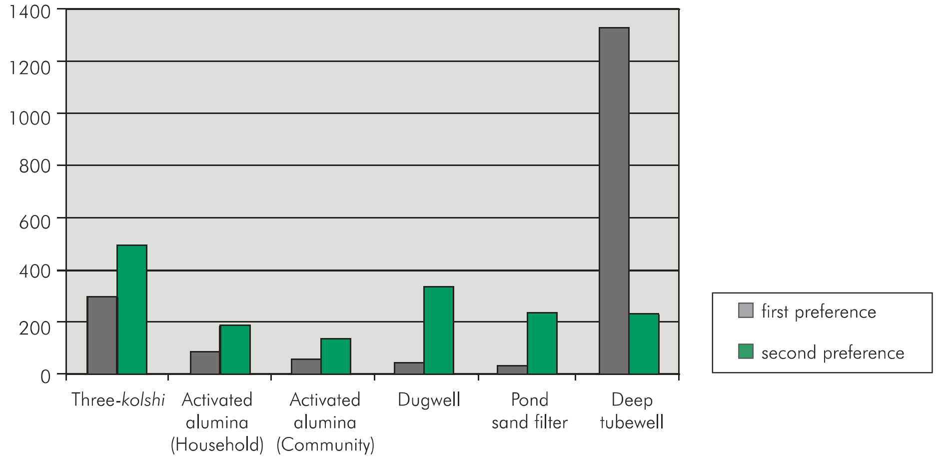

Figure 4 Household ranking of the six selected arsenic mitigation technologies (WSP-Worldbank, 2003)

Dug wells are also found in Bangladesh, though they are not as common as before the installation of shallow tube wells. Shallow tube wells are drilled until below the upper clay layer, making them microbially safe(r) for drinking water. Dug wells aim at the phreatic aquifer above this clay layer, where the water is not protected as well against microbial contamination. However, since this upper groundwater layer is directly replenished by rainwater it tends to be free of arsenic, (although it may contain dissolved salts.

Alternatively there has been a campaign to share *shallow tube wells* with neighboring households that have arsenic- and salt-free tube wells (<50µg/L, painted green; van Geen *et al.*, 2002; Ahmed *et al.*, 2006). Although this campaign was effective, it was also found that continued monitoring of tube wells is required in order to assure that knowledge about arsenic-free tube wells is not lost (Balasubramanya et al., 2013; George et al., 2012). Visualization of arsenic contamination can aid in consumer awareness and behavior change. In a recent publication (Biswas et al., 2012) it was proposed the use discolored tube well platforms to identify arsenic contamination, i.e., orange colored platform represent iron-containing, and potentially arsenic-containing, tube wells.

A key disadvantage of targeted wells, well switching and most desalination technologies is that households do not have the water source on their premises. A promising intervention that combines targeted wells and household water delivery are *small piped networks*. In Bangladesh the willingness to pay for water is low (WSP-Worldbank, 2003), except for piped water solutions (BWSSP, 2011).

2.3.3 Treatment of arsenic- and salt-containing groundwater

In case of targeting safe, arsenic- and salt-free groundwater is not an option it is worth considering the treatment of arsenic-or salt-containing groundwater. Although arsenic and salt removal from water is not an easy task, this groundwater source still has a key advantage over surface water: microbial safety.

When it comes to the selection of an arsenic or salt removal technology, many aspects have to be taken into account, with economic factors among the most important ones. The population to be served and its condition in terms of health and economic status, lack of safe water, and other socioeconomic parameters are also important aspects to be considered. Expensive techniques cannot be applied in populations with low economical resources, because such techniques require monitoring and maintenance which can make the process even more expensive and thus not sustainable in the long term. In a recent study Etmannski and Darton (2013) assessed that cost, trust, distance between home and the clean water source (an indicator of convenience), and understanding the health effects of arsenic represented the 'most important' issues as specified by the technology users.

From a technical point of view, the water matrix composition (i.e., its physicochemical and microbiological characteristics) together with the availability of materials and infrastructures in the area will be essential in the decision of the As or salt removal technology to implement. Many of the processes already in use are reliable, but only if applied in the right circumstances (Kartinen Jr and Martin, 1995; EPA, 2007) and taking into account the needs and acceptance of local population.

Conventional, well-established as well as emerging technologies for arsenic and/or salt removal are included in this report, categorizing the various processes accordingly to their remediation principle. When applicable, available household applications operating with such remediation principles are mentioned:

- Oxidation of arsenite (section 4.1)
- Precipitation,coagulation, and filtration (section 4.2)
- Adsorption and ion exchange (section 4.3)
- Membrane-based technologies (section 4.4)
- Biological processes (section 4.5)
- In-situ remediation (section 4.6)
- Treatment of brackish groundwater (section 4.7)

Each arsenic and/or salt removal technology has its own distinct (dis)advantages and no solution will fit all conditions. It is therefore essential to assess the local conditions, - such as demand, water quality composition and economic resources – before deciding in what technology has the greatest potential. For example, arsenic typically occurs as As(III) in the anoxic groundwater sources of Bangladesh, whereas some technologies are only capable of removing the oxidized state of As(V). Another key challenge is the co-occurrence of elevated iron concentrations, because although iron precipitation may aid in arsenic removal, it may also cause clogging to many of the technologies (e.g., that rely on filtration). Lastly, the co-occurrence of other anions in the groundwater is very common in Bangladesh (such as phosphate and bicarbonate), which can seriously inhibit the efficacy of technologies that rely on adsorption or ion exchange. Therefore, when considering the implementation of new, emerging technologies it is crucial to include a pilot phase where the technology is assessed in different natural groundwater settings in Bangladesh. In many cases, a single technology will not suffice in the removal of arsenic and/or salt – either due to the need for pre-treatment (e.g., oxidation), post-treatment (e.g., re-mineralization) or treatment of a waste stream (e.g., concentrate). When assessing the sustainability of a technology it is important to consider all of the above instead of the stand-alone technology only.

In the coastal areas of Bangladesh, the targeting of arsenic- and salt-free water has serious limitations, as the underlying aquifer contains brackish groundwater. Salt water intrusion is a serious problem in this delta country. In these southern regions rainwater harvesting has an increased potential and it may be worth considering solar energy utilizing *desalination technologies*, such as reverse osmosis or evaporation technologies. In general, implementation of these technologies are relatively expensive, but innovations are underway to reduce costs (e.g. through local manufacturing).

In Bangladesh there has been extensive experience with the implementation of household water treatment and storage (HWTS). This so-called point-of-use water treatment, greatly reduce the risk of recontamination of the treated water during transport (Sobsey, 2002). HWTS treats the water in homes to remove microbial and/or chemical contaminants, and it has been recognized to be an effective measure in reducing diarrheal diseases (Sobsey, 2002; Fewtrell et al., 2005; Clasen, 2008; Hunter, 2009; van der Laan et al. (2014)). Most arsenic HWTS solutions consist of buckets on a tripod and appear to be similar, but reported efficacies vary widely between <30% to >90% (Sutherland et al., 2002; IGRAC, 2007; BETV-SAM, 2011). Many factors influence removal efficacies (e.g., water quality and consumer operation), but before the implementation of HWTS one must have solid and statistically valid results showing that it is a safe technology. Several studies pointed out that most of the proposed arsenic removal units failed to perform according to the set guidelines (Sutherland et al., 2001; IGRAC, 2007). Additionally, the post-deployment monitoring is generally poor or absent. Nevertheless, there are arsenic HWTS solutions that show potential, provided that capacity building and behavior change campaigns accompany their implementations (Mosler, 2012). If HWTS is the chosen option, then regular monitoring of the quality of removal is of key importance. As long as these methods are not adequately embedded in the daily social practice of participating households, then more central organs such as NGO's or state-related institutions need to monitor and advise users on the proper use of HWTS devices.

2.3.4 Appropriate non-groundwater alternatives

In most cases groundwater abstraction and treatment is preferred over other water sources, as it generally provides a constant water quality and is free of pathogenic microorganisms. However, in some cases groundwater is not available, accessible or of sufficient quality; requiring water collection from alternative sources. A decentralized option would be the harvesting and storage or rainwater. Especially in regions with significant rainfall, such as in Bangladesh, this option has the potential to be a safe arsenic- and salt-free alternative. Nevertheless, there are some challenges related to this water source, such as seasonal availability and (microbial) contamination during collection and storage. Rainwater harvesting and storage has been practiced in Bangladesh (Hoque et al., 2004; Islam et al., 2010), and according to an NGO Forum study preferred by consumers over dug well and several arsenic removal techniques (Heijnen, 2002).

A second alternative source for drinking water would be fresh surface water, from rivers, lakes or ponds. In general, surface water has a fluctuating water quality and contains many different contaminants, including suspended solids, pathogenic microorganisms and pesticides. In order to target such a wide range of human health threats it is desired to install a multi-barrier system; where more than one barrier exists for each contaminant. Currently most *appropriate* technologies for surface water treatment focus on disinfection, as pathogenic micro-organisms pose to largest health threat to humans (diarrhea, cholera, hepatitis).

The appropriate non-groundwater alternatives are included in the following categories:

- Rainwater harvesting and storage (section 5.1)
- Surface water treatment (section 5.2)
- Natural engineered systems (section 5.3)
- Evaporation technologies utilizing solar energy (section 5.4)

For *surface water treatment* the emphasis will lie on household and community water treatments that typically utilize coagulation-flocculation processes followed by filtration and disinfection methods (UV-disinfection, chlorination or boiling). Important to note that especially HWTS methods offer a wide range of combinations of these methods. This book describes each basic process but puts emphasis on the application of community-level solutions. Household-level versions of these treatments share most of the eligibility characteristics and are therefore offered as groups instead of specific methods.

Natural engineered systems are a group of technologies that rely on the disinfection and filtering properties of a sandy subsurface. River bank filtration consists of a gallery of vertical or horizontal wells along a lake or river bank and abstracts a mixture of surface and groundwater. With sufficient retention time of the surface water in the subsurface, the water will be clear and microbially safe after abstraction. Similar technologies have been applied in Bangladesh, namely infiltration galleries by WaterAid Bangladesh (2006) and artificial aquifers by Practical Action Bangladesh. Managed Aquifer Recharge (MAR) and Artificial Recharge and Recovery (ARR) rely on the same principle, as rain or surface water is infiltrated or injected into the subsoil. The subsurface functions as a large storage facility, assures water quality improvement and reduces peak concentrations of contaminants (mainly dissolved solids). There is a growing local experience (at DPHE, Practical Action Bangladesh, UNICEF Bangladesh, Dhaka University and smaller NGOs) with the injection of rain or pond water into the subsurface in Khulna and Shatkhira (Acacia, 2011).

Evaporation or distillation technologies can be used to treat any kind of contaminated water, because it separates water from its contaminant in the gas phase. Appropriate technologies have been developed as low-cost alternatives, including the WaterPyramid or solar stills. In general, the economic balance for evaporation technologies is negative and possible recontamination prompts the need for disinfection.

2.4 Matching context and eligibility – the ASTRA tool

The matching of context and eligibility is executed with the comparison of identified context factor options (stage 1) and the technical methods developed for the second stage of the ASTRA tool. The core of the eligibility matching or screening comprises 25 methods complete with multidisciplinary descriptions that form a practical knowledge base and the related eligibility matrices that include the functional range of each method.

2.4.1 Classification of the knowledge base

In the framework of the ASTRA project, 26 technology information sheets (Figure 5) were developed that form the practical knowledge base of the tool. To enable efficient matching of project context and eligibility, each of the methods is described according to a strict framework of disciplines. This classification simplifies locating of information relevant to the tool user and reduces the time required to assess a method’s relevance in any project or policy context. The eight sections were defined with the help of previous decision-support tools (Szántó *et al.*, 2012) and the FIETS theory developed by member organizations of the Dutch WASH Alliance (Text box 1). Their FIETS approach served as the guide to the formulation of financial (F), institutional (I), environmental (E), technical (T) and social (S) sections.

SD-01 Deep tube well

Category	Content
DESCRIPTION	A deep tube well (DTW) aims to abstract water from a deep water layer (aquifer). The depth depends on the geographical and geo-hydrological situation, per definition the water comes from a water layer below an impermeable or confined layer. Drilling the wells might be conducted with manual or machine drilling techniques. After drilling, a PVC tube is placed as casing, with at the lower side a filter. The DTW is mostly equipped with a handpump for abstraction, but it is also possible to use a motorized pump. In the last case it might be extended with a small piped supply network.
APPLICABILITY	Deep tube wells are more high-tech than other well options, since more advanced drilling techniques are required (in some cases stone or rock cutter (Diamond cutter)). The depth of DTWs varies from 100-300m. The DTWs are mainly constructed for communal use. Its main strength is the water quality, both in terms of biological and chemical contaminations. Deeper water layers do mostly not contain arsenic and iron.
REQUIREMENTS	Drilling a DTW requires suitable drilling materials. In sandy grounds (e.g. southern part of Bangladesh) drilling can be conducted with manually drilling techniques. This requires mainly time and human effort (about 10-12 days with 7 laborers), besides some basic materials. In case of harder soils, machine drilling is preferred. These machines might be mounted on a truck or trailer and may be accompanied by large compressors or mud pumps. Maintenance of the tube well itself is minimal. Only the maintenance of the pump requires technical skills.
FINANCIAL	A 300m deep tube well might cost about 500-700 USD, if drilled manually. In case of machine drilled wells, per unit costs might be >1000 USD. O&M costs are estimated to be very minimal, some 1-3 USD per month.
INSTITUTIONAL	The well drilling can best be done by a specialized company or trained local mason group. They are usually hired by the implementation program. For wells that are drilled by machine, it is common to do a geo-physical survey by a geo-hydrologist to determine the site with the best potential, drilling depth, drilling method and expected yield. The management of the well does mainly relate to the pump maintenance. In case of communal use, a management committee might be formed to take the responsibilities.
ENVIRONMENTAL	Deep tube wells feature good quality water and resilient well construction if well specified in contracts. Increasing the number of deep wells in an area may result in the lowering of groundwater level. Design needs to anticipate on low water levels during dry periods. The risk of collapsing is low, deep tube wells can deal with heavy rains.
TECHNICAL	Construction of a deep tube well can be done in several days with manual drilling or in one day with machine drilling. Drilling in sand is often conducted with jetting: water is pumped through a drilling pipe, eroding the soil. Water and cuttings are transported up between the drilling pipe and the borehole wall. This drilling requires less technical skills than machine drilling in harder soils. For the latter one a supervising specialist is required.
SOCIAL	High acceptance level by users due to good quality drinking water. The constructed deep wells offer an ideal public health improving solution in areas where both surface and shallow groundwater is contaminated. However, a water quality test is recommended. Equipment for pumping might include sophisticated technologies that make local maintenance difficult.
BANGLADESHI APPLICATIONS	DTW is a safe water option in many regions in Bangladesh. In 2009, the number of DTWs in Bangladesh was about 162,000. Since then this number has rapidly increased and it is still growing.

Eligibility matrix of the deep tube well method

WATER SOURCE	Rainwater	Surface water	Brackish water	Groundwater	
REMOVAL	Arsenic	Salts			
LOCATION	Densely populated urban	Densely populated, low-income urban	Moderately populated urban	Peri-urban, rural	Rural, remote
SITE SELECTION	Not relevant	Settlement	Agricultural	Coastal	
SCALE OF IMPLEMENTATION	Household	Shared	Small community	School or institution	Large user group
PREFERRED LEVEL OF WATER DELIVERY	Household	Shared	Small community	School or institution	Large user group
PREFERRED MANAGEMENT LEVEL	Household	Shared	Small community	Municipal	
STATUS IN BANGLADESH	Widespread	Known	Little known	Unknown	
SYSTEM SOPHISTICATION	Labor-intensive	Intermediate	Technology-intensive	No preference	
GROUND FORMATION	Sand & gravel	Clay formations	Compacted formations	Soft weathered rock	Bedrock
	Unknown				
WATER LIFTING	Not required	0-8 m	8-15 m	15-40 m	> 40 m
	Unknown				
WATER TRANSPORT	Manual	animal	Small-scale	Large-scale motorized	
ENERGY AVAILABLE	None	Electricity grid	Fuel generated	Solar energy	Wind energy
FLOOD DANGER	Not affected	Only flooded in extreme weather	Annually affected by floods		
ACCESS TO SITE	On parcel	Outside of household area	Less than 10 minutes to access	Less than 30 minutes to access	More than 30 minutes to access
CONSTRUCTION COSTS	Negligible	Less than USD25	USD25-100	More than USD100	
MAINTENANCE COSTS	Negligible	Less than USD5 per month	More than USD5 per months	More than USD100 per month	
TIME NEEDED TO CONSTRUCT	Insignificant	A few hours	A day	Several days to a week	Weeks
LEVEL OF EXPERTISE IN O&M	Household	Local technician	Local government	External experts	
USER ACCEPTANCE	No activity	Limited extension	Considerable extension	Extensive campaign	

Figure 5 The technology information sheet (left) and the eligibility matrix(right) of the deep tube well method

- **DESCRIPTION**

This section includes a concise definition of the method and its key features. It explains briefly the functioning and the key parts or units of the related device or installation. If a method-group is described, like in case of HWTS methods, then the key proponents, e.i. specific brands and designs are mentioned.

- **APPLICABILITY**

The section ‘Applicability’ details the optimal utilization and the key boundaries of the methods in the specific, Bangladeshi context. The text explains the level of optimal application (such as (shared) household vs community- or municipal-level); the level of technical complexity (high-tech vs low-tech); the functional range and the key strengths and weaknesses of the method.

- **REQUIREMENTS**

In this section, the key requirements of the implementation and use of the methods are described. Such information includes the number and type of experts and labor required for the installation; the number and type of employees for management and maintenance of the implemented method and the related level of expertise needed. In addition, requirement from the user such as the daily efforts for maintenance (in case of HWTS) and expected queuing or fetching time are also mentioned where possible.

FIETS SUSTAINABILITY PRINCIPLES

Financial sustainability means that continuity in the delivery of products and services related to water, sanitation and hygiene is assured, because the activities are locally financed (e.g. taxes, local fees, local financing) and do not depend on external (foreign) subsidies.

Institutional sustainability in the WASH sector means that WASH systems, institutions, policies and procedures at the local level are functional and meet the demand of users of WASH services. Households and other WASH service users, authorities and service providers at the local and the national level are clear on their own roles, tasks and responsibilities, are capable of fulfilling these roles effectively and are transparent to each other. WASH stakeholders work together in the WASH chain through a multi-stakeholder approach.

Environmental sustainability implies placing WASH interventions in the wider context of the natural environment and implementing an approach of integrated and sustainable management of water and waste(-water) flows and resources. WASH interventions connect to and affect the natural environment and hence people's livelihood.

Technical sustainability of WASH services is reached when the technology or hardware needed for the services continues to function is maintained, repaired and replaced by local people and it is not depleting the (natural) resources on which it depends for it's functioning.

Social sustainability refers to ensuring that the appropriate social conditions and prerequisites are realized and sustained so the current and future society is able to create healthy and liveable communities. Social sustainable intervention is demand-driven, inclusive (equity), gender equal, culturally sensitive and needs-based.

Text box 1 Sustainability principles. Source: Dutch WASH Alliance portal (DWA, 2014). Courtesy of the Dutch WASH Alliance Secretariat

- **FINANCIAL ASPECTS**

This section describes financial and economic information relevant for the construction or implementation, and the operation and maintenance (O&M) phases. The O&M information also includes the frequency and extent of capital and maintenance expenses (where possible). Where a method is directly applied by users, the indication on the user fee is added. In some cases, the potentially effective financial strategy for efficient dissemination is included; just as the general indication on affordability and economic sustainability (based on past Bangladeshi or international experience).

- **INSTITUTIONAL ASPECTS**

Relevant institutional settings and policies are included in this section together with issues of facility management. Depending on the availability of Bangladeshi or international data, the optimal level of management (household-, community- or municipal) is described. Requirements as the establishment of a local committee or the preference for professional managing are indicated.

Where possible, the ways and requirements to integrate the method's operation into the existing institutional framework are also included.

- **ENVIRONMENTAL ASPECTS**

This section has its primary focus on the relation between the implemented method and its natural surroundings; i.e. the characteristics of its water catchment area or other natural environment. It includes risk of (over-)abstraction and level of recharging, potential contaminations related to the method location and the risk of reduced livelihood as a result of implementation. As much as possible, this section also tried to indicate climate change consequences, e.g. vulnerability to heavy rains and severe droughts.

- **TECHNICAL ASPECTS**

This section includes a summary of the most important technical issues regarding construction, operation and maintenance. Construction, but especially O&M activities and key technical parts requiring frequent change or maintenance are given. Information on the technical capacity is completed with key requirements for setup and operation, and the frequencies for the changing of key units or parts in the method.

- **SOCIAL ASPECTS**

In this section, social and hygiene-related information is provided. This includes social behavior and daily practice issues related to the sustainability of each method, just as the level of user preference and any significant improvement that may be expected from the appropriate use of the methods. As some of the included methods require frequent actions from the users, this section informs the tool user on these (including e.g. pumping or household treatment and storage activities).Further, indications are given on whether awareness raising campaign or frequent monitoring is also to be integrated into the implementation process. The level of indicated willingness-to-pay and specific gender information is given, where the collected literature or the interviews supported credible data.

- **BANGLADESHI APPLICATIONS**

This final section in the technology information sheets shows the relevant Bangladeshi applications in the past. Extent of application and – where possible – success and failure rate indications are included in the text. The project or program related to the implementation and eventual experiences of the method complete this section.

2.4.2 The eligibility screening

Each of the 26 methods is completed with an eligibility matrix (see Figure 5 for example) that demonstrates how the method functions in relation to the 21 screening factors and their options. These matrices were developed in the framework of the ASTRA research and can be seen as the organized performance tables for the methods to support the rapid identification of applicability against the user-specified context factors. Assessment of method functioning against each of the described factors (and the contained scenarios) can be executed manually using the current publication (chapter 6 and ANNEX 1). Eligibility screening can also be executed with the attached ASTRA decision-support tool software.

This eligibility screening is in essence a multicriteria analysis that offers an aggregated, multi- or transdisciplinary output on method eligibility. This eligibility output is kept simple in order to ensure that tool users can understand which aspect(s) of a method are fully or only partially eligible. In the ASTRA tool, functioning is classified into four distinctive categories:

- **Appropriate,** indicating that the option is appropriate according to the scenario viewed,
- **Appropriate with restrictions,** indicating that the technological option may be suitable for that scenario, but it is likely to function sub-optimally,
- **Not appropriate,** indicating that the method is unlikely to function in a resilient way according to the viewed scenario.
- **Not relevant,** indicating that the scenario does not influence eligibility of the viewed method.

Once the eligibility screening is executed, the tool user is required to view and analyze the output. In an optimal case, a method may score appropriate for each factor in the developed context scenario, making it fully appropriate for that setting. More often, some of the viewed factors are likely to be only partially eligible or non-appropriate. As a result of the simple 'decision-tree', a clear indication on appropriateness is given as the user can immediately identify the specific factors that do not suit applicability. Depending on the type of context factor (natural, human or technology-related) a basic advice is provided on the potential of changing the factor to the advantage of sustainable implementation and (in the digital tool) a brief remark is offered on the concrete reason of ineligibility.

With this feature, the developed tool offers a robust and transparent way of decision-support to make it relevant in any Bangladesh water project setting. This does not only include the selection amongst potential new mitigation methods, but can also aid the viewing of currently malfunctioning options as well. By applying the ASTRA tool for such installations or devices, the user can receive indications on whether an existing method is worth to renovate or upgrade or that a more appropriate alternative should replace it.

2.4.3 Determining the pool of potential methods

In an optimal situation, the eligibility screening immediately indicates the method that is potentially the best choice for the assessed context. In most cases however, more methods are expected to remain eligible after the screening. These methods require an additional step to identify the final method of choice. In such situations, the user first needs to determine a pool of potential methods for the final selection process. This pool of eligible methods may be formed from those options that are eligible according to all of the screening aspects. However, methods with partial eligibility may also be included if their presumed limitation(s) are considered either irrelevant or manageable in the specific project context. This decision is left with the user; the role of the tool is to highlight the limiting factors for his consideration. After these limitations and potential trade-offs are assessed, the user can make an inventory of the remaining methods for a final selection.

Regardless of the reason for method selection, it is advised that the final selection is executed in cooperation with other stakeholders. The ASTRA approach and tool supports the decision-making process only until the determination of the pool of potentially eligible methods. As the ultimate selection remains with the user, it is recommended to be done in consultation with other project partners and especially with the inclusion of future beneficiaries of the method. Regardless of the method chosen, this participatory approaching of the final method selection phase is expected to increase the chances of method resilience after implementation.

2.4.4 Method selection and post-implementation assessment

At present, participatory processes are often recommended for the ultimate stage of water method selection but in practice they are not commonly applied (van Buuren, 2010). The ASTRA approach does not set limitations to this last phase when the pool of eligible methods is reduced to one preferred choice. Instead, it proposes a flexible discussion round where each method's strengths and weaknesses are discussed in a multistakeholder process.

The lack of an additional protocol may seem contrary to the systematic efforts set at previous steps. However, the ASTRA approach for the (ultimate) method selection stage operates with the assumption that final choices in method selection may become so complex that a straightforward procedure would possibly be more restriciting than supporting. Therefore this approach guides and frames the final selection process only through the systematic method descriptions and context factors. The main task of project stakeholders is to critically view whether all screening results are of concern for them. As the tool describes typical applicability of the different water methods, there may be differences between the importance of limiting factors after the screening. Without imposing more rules, this process is guided and supported by the common platform offered by the method descriptions and the structuring of information.

Once a method is selected and implemented, it is advisable to follow up its quality of implementation and actual use. This assessment stage falls outside the scope of the current approach as the ASTRA tool is concerned primarily with method applicability. Also, several potential tools exist that are designed specifically to evaluate WASH initiatives. One of the latest and potentially most compatible instruments is the Technology Assessment Tool (TAF) of the WASHTech programme (at www.washtechnologies.net/en/taf/how-to-use ; Olchewski *et al.*, 2012). This tool is designed to aid application and assessment of resilient WASH methods. It does so through the creation of an evaluation framework that matches the local 'need' for a (water) technology with method 'applicability' (functional range) in a multistakeholder context. As such, it may already be applicable in the method selection stage of the ASTRA process, but it is expected to be most useful in the post-implementation stages.

In the post-implementation phase, stakeholders normally develop a monitoring and evaluation strategy. This is where the TAF can optimally compliment the ASTRA tool as it operates with local visits, bilateral interviews and focus group discussions. These activities – together with the necessary training of TAF moderators – are expected to be relatively easy to integrate in the project planning. The achieved results from TAF can be directly fed back into the project as all stakeholders have been involved in the evaluation process. In addition to project improvements, the TAF can support the updating of ASTRA when the context factors and the method eligibility matrices are also viewed during the multistakeholder discussions.

2.5 Intended users and use of the ASTRA approach

2.5.1 Decision-makers and practicioners

Policy and decision-makers often require concise information that can quickly inform them on the most relevant details of a problem. In the currect context, the ASTRA approach offers critical reviews of fundamental methods and summaries of practical information on a large number of purification and supply methods. This is expected to offer relevant information to those who need to determine specific mitigation approaches for any locality or region. The added reference list and the inventory on active arsenic- and salt-mitigating organisations in Annex 2 can help decision-makers to approach experts for further information.

2.5.2 Multistakeholder processes

The technology information sheets and the coupled performance assessment tables are possible to utilize in focus group discussions and multistakeholder processes. In the first setting, future users can analyze their method preferences under the guidance of a water professional. The proact-type approach of van Buuren (2010) and Hendriksen *et al.* (2012) is a good example on how to execute a participatory decision-making process wherein users identify the potential method of choice by comparing their preferences and the functionality of the included methods. In such processes, the ASTRA technology information sheets can aid the rapid identification of the strengths and weaknesses of methods to help achieve a realistic trade-off between user preference and actual applicability.

In the multistakeholder context, the ASTRA tool can be used for the joint viewing and evaluation of eligible methods by all stakeholders. In this setting, the ASTRA tool can aid decision-making by offering an objective source of information to evaluate differing views on functionality. Naturally, users can still deviate from the suggested eligibility boundaries, but at least they view their opinions against the ASTRA 'baseline'. As subjective opinions are evaluated against reviewed method information, the application of the ASTRA tool can make water method selection more objective.

2.5.3 Education and research institutes

The systematic description of method fundamentals and performance assesments make this book a potential tool for education. The offering of a comprehensive compendium of water methods for Bangladesh can aid the academic or practical training of future water professionals.

2.6 Quality of the approach

The ASTRA approach is in essence a sourcebook and decision-support tool. This implies that it is not meant to replace water experts but to aid them in identifying the best choices. The ultimate choice for a mitigation method remains in the hands of the tool user. This is a crucial feature of the approach and it is based on the acknowledgement that in reality no strategy can account for every local alteration in the functionality of a method. This feature makes the tool adaptive to uncommon situations where the functionality of a method may be slightly different to what is generally expected. To offer an example: a centralized treatment method may be, in general, inappropriate for a rural/remote community. However, specifc circumstances may make this method eligible for such a location. Using the ASTRA tool, an expert or a project group may therefore decide to deviate from the advice of the tool and select the method if it fits all other aspects.

The screening process is simple as it operates with a one-step multicriteria analysis. This simplicity has a key positive feature for the identification of the most appropriate mitigation methods. This feature is transparency. In this context it means that anyone using the tool can identify why a certain method is chosen to be eligible or not in a given context. Considering the complexity in a real selection process this is expected to contribute to the optimal decision-making process of the tool user.

The simplified screening process implies that its quality is primarily based on the quality of its content. To achieve that, the content needs to be based on reliable information. In the ASTRA tool this is achieved through the using of peer reviewed and expert tested data and facts in both the description and the applicability of the included methods. By using scientifically proven and field tested information, the tool information can be considered relatively objective. This objectivity is a key positive feature of the tool. The exposure to new technologies and increased objectivity in the selection procedure can motivate users (local and WASH experts) to learn of and consider, otherwise disregarded, alternative technologies and (ii) achieve a higher level of appropriateness in the project design, thereby improving the overall project sustainability.

The key features of this type of decision aid can be summarized as

- decision-support instead of –making
- an extensive and objective knowledge base of potential mitigation methods,
- a simple and transparent decision protocol,
- the offering of a consistent format for collecting new information on future methods.

The tool is specifically designed to mitigate the As- and salt-problem, not for general water supply application. It is expected that the method description remain valid in a Bangladeshi context (and partially even outside that), but caution is advised when using tool outside the arsenic- and salt-mitigation scope.

Limitations to the method application include the lack of quantification on the number of units or actual size and costs of the selected method, the inappropriate use of the tool and the neglecting of the offered decision-support. The first limitation implies that relevant design calculations need to be sought outside of the scope of this book. The second risk to tool use can be minimized through the application of detailed method assessment tools such as the earlier mentioned WASHTech or WASHCost tools. The last risk, the neglecting of the offered decision-support is perceived to be the main risk to the tool. Especially if experts are involved in the decision-making process of a water method selection, then it is possible that the tool information will either not be used or will be neglected. Such situations may not necessarily lead to inappropriate choices, but tool use should be encouraged to increase objectivity in the determination of the potentially best mitigation method(s).

3 Targeting arsenic-free groundwater

Technology information sheet	SD-01 Deep and intermediate tube well SD-02 Dug well SD-03 Shallow and shrouded tube well SD-04 Well switching CO-01 Piped water supply schemes

From the 1970's NGO's and government departments of Bangladesh have opted a major shift from the use of surface water to groundwater (WHO, 2011) to enhance the decline in diarrhoeal diseases. Although the approach reduced prevalence of diseases, the high level of arsenic frequently found in shallow groundwater in Bangladesh is now one of the major challenges to be solved. 1 out of every 5 tube wells appears to be contaminated (Unicef, 2008). The British Geological Survey (BGS) argues that many valleys have been filled up with sediments such as grey clays that hold arsenic. Older brown alluvium such as in the Northwest or hilly regions is less contaminated. Much of Bangladesh consists of 2 overlying aquifers, a shallow one (first 70meters) and a deeper one that is separated by a layer of clay (Scientific American 2004). Figures estimate that about 10 million wells are located in Bangladesh that tap into the groundwater for drinking water consisting of open wells (hand dug), shallow tube wells and deep tube wells. Generally, the shallow aquifer is most often polluted with arsenic.

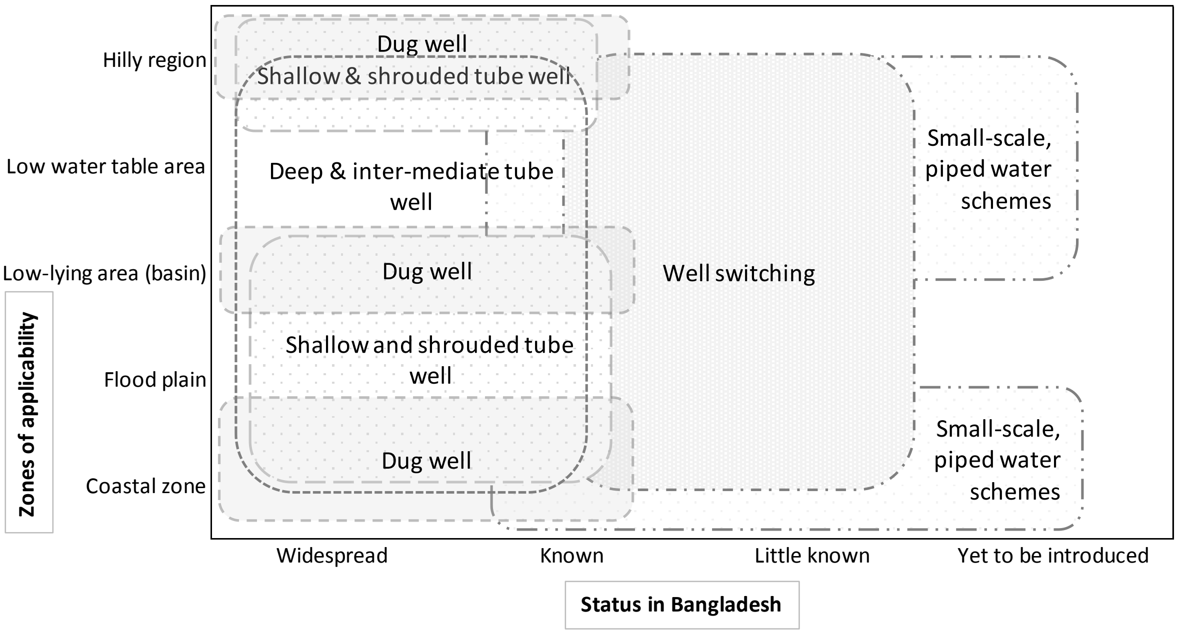

Figure 6 (Potential) use and experience of the identified direct, groundwater abstraction methods in Bangladesh

Figure 6 contains the relevance of direct, groundwater abstraction methods for different zones in Bangladesh. According to literature, different well structures (and related abstraction) are widespread in practically all zones. Well switching, which is not a separate water supply method but an efficient mitigation approach, is indicated to be known in most areas. Small-scale, piped water schemes are location dependent. In some areas there seems to exist much experience with their sustainable use, in other areas they were never tried with success.

3.1 Deep and intermediate tube wells

Technology information sheet	SD-01

Highlights – Deep tube wells are the most widespread and one of the safest arsenic- and salt-mitigation solutions in Bangladesh. They are widely accepted and their implementation is affordable in most contexts. The key limitations of this method include their dependence on location of the aquifer, ground formations impossible to drill manually and price. Overabstration of the deep aquifers is not (yet) prevalent. Contamination from shallow aquifers might be reduced if applied in combination of shallow aquifer utilizing irrigation.

There is not a general law for the classification of the depth of wells between shallow and deep when the technical execution is considered. Utilizing similar methods, the main difference lies in the aquifer utilized. Internationally, wells that are less than 15 meters deep are often referred to as shallow, though in Bangladesh shallow wells are classified by Department of Public Health Engineering (DPHE) even when they exceed 75m. Deep wells have been found to be relatively free from arsenic contamination. A BGS and DPHE study has shown that only about 1% deep tube well having depth greater than 150 m are contaminated with arsenic higher than 50μ g/L and 5% tube well have arsenic content above 10μ g/L (BGS and DPHE, 2001). Approximately 165 000 deep wells have been installed in Bangladesh (both manually and by machine) which are over 150 m deep.

A potential risk is presented in areas where shallow and deep aquifers do not have an impermeable layer in between (e.g. clay layer or rock formation) and which are now being connected by drilling. This could eventually lead to arsenic contamination due to mixing of upper contaminated layers with lower uncontaminated layers. If recharge occurs through horizontal movement and filtration the deeper aquifer is likely to be arsenic free. Sanitary seals (grout, bentonite pellets) along the casing pipe and capacity building of both hand drilling and machine drilling enterprises is important to overcome this problem.

Tube wells generally have diameter of 50-200 mm. Depending on the formation that needs to be penetrated a drilling method is chosen. The thick layers of sediments in Bangladesh are often very soft and heavy machinery such as down the hole hammers or mud rotary systems are not always necessary. Depending on the depth and formation to drill, a hand drilling could also be applicable that could significantly save on costs. Once the required depth of drilling is reached, the drilling pipes are removed and a casing (tube) is installed. The water is drawn from a filter attached to the casing. Some areas of the coastal region of Bangladesh are very suitable for construction of deep tube wells.

The DPHE has realized 81,384 deep tube wells in Bangladesh until 2000 (DPHE, 2000), and more were developed since then. In 2009, the number of deep tube wells was reported at about 162,000. This overall popularity of the method to mitigate arsenic and salt problems indicates that overabstraction of deep aquifers may occur. Such a risk has not been indicated so far. Michael and Voss (2008) assessed that deep tube well abstraction may serve as a sustainable source only if water is used for drinking and domestic purposes only. A key risk in sustainability was identified as the susceptibility of deep aquifers for arsenic and salt contamination from shallow aquifers. Their assessment indicated that this risk could be reduced if deep tube well use was complimented by the enhancing of shallow aquifer utilization through irrigation. Possibly, this irrigation practice could contribute to the limiting of a downward migration of arsenic contamination, but it should be kept in mind that such a practice would also magnify the exploitation of these water sources. In areas where no impermeable layer exists between shallow and deep aquifers, sanitary seals (grout, bentonite pellets) should be added along the casing pipe. Monitoring of the deep aquifer should be done to control the threat of aquifer contamination.

3.2 Dug well

Technology information sheet	SD-02

Highlights – A simple to implement design, but only where shallow aquifers supply contamination-free water. Arsenic contamination is unlikely, but pathogen concentrations are expected to be high for drinking use in most Bangladeshi regions. Additional salinity contamination is expected, especially in the coastal areas of the country.

Hand dug wells are range in diameter from 80 cm to several meters depending on the country and use. Hand dug wells are often referred to as shallow wells and are usually within the range of 15 m deep, but lined wells up to 40 meters are also present.. Both types use shovels and picks to cut the formation and buckets or bags to bring it to the surface. Often a windlass is used for the lifting of the bucket to the surface. The work is simple for shallow depths, but becomes more complicated below 15 meters, this counts especially if it is below the unsaturated zone. In such case there is limited oxygen for the diggers and the risks increase for collapsing walls. In the saturated zone, dewatering pumps are needed to dig inside the aquifer. In unstable formations and wells that are being used for larger groups, the wells are often lined to bring stabilization to the well walls to prevent them from collapsing. Metal drums, concrete rings or bricks are used for lining. The depth of the well depends on the level of the static water table and the season of digging. Usually the depth of the well is 1 or 2 meters below this level in the dry season.

A hand dug well is more difficult to protect from contamination than tube wells as the sealing of the well walls is difficult. A hand dug well is often open at the top, but can also be protected by an apron that prevents percolation from the top. Especially if a rope and bucket is used for water withdrawal, contamination of the well is unavoidable. Hand pumps can also be placed on hand dug wells that prevent re-contamination by the users. In many places in Bangladesh the tube well has replaced the hand dug well, though it is estimated that more than 1mln people still rely on hand dug wells for their water supply.

Hand dug wells are lower in cost than machine drilled wells and very useful in formations with a low permeability due to their capacity to store water which seeps in through well walls overnight. However, the total yield may be low, and water quality may be poor because the water comes from an open source, allowing pollutants to enter easily. A hand dug well, lined with concrete rings preventing it from collapsing, has a high yield, but often the price will come close to that of a machine drilled well (PRACTICA, 2010). In Sylhet, Chittagong and northern parts of Bangladesh hand dug wells are common due to the presence of stony formations that are difficult to drill by hand.

Precautions should always be taken that the yield of such wells can be too low for communal use and water tables too deep for proper construction (Ahmed, 2002).

The water quality from a hand dug well can often be found to be free from dissolved arsenic. This has probably to do with the oxidation process in a hand dug well where it is open to the air and can cause precipitation of dissolved arsenic and iron. In addition, dug wells accumulate groundwater from the top layer of an aquifer which is replenished each year by arsenic safe rain and surface waters by percolation through the aerated zone of the soil. The fresh recharges also have diluting effects on contaminated groundwater (Ahmed, 2002).

Bangladesh is one of the few countries in the world where manual drilling is also used to drill deep wells. Jetting practices are used that require a circulation of water to bring the cuttings to the surface. Jetting works excellent in soft and loose formations such as sands silts and clays. There are examples in Bangladesh that wells have been drilled manually upto 300 meters. If manual drilling could be used to drill wells to a second aquifer (in places where appropriate), being in most places deeper than 70 meters it could overcome the problem of arsenic contamination. Sealing of the wells is then critical and the local operators will require training for an adequate execution.

3.3 Shallow and shrouded tube wells

Technology information sheet	SD-03

Highlights – Shallow and shallow shrouded tube wells share features with dug wells but they are more compatible with (hand) pumping methods. Shallow wells are optimally applicable where shallow aquifers are free of contaminations. Expected costs are higher than for dug wells, but the quality of the wells for abstraction is also higher.

Manual drilling is a practical and affordable solution for wells that are generally less than 40 meters deep in alluvial soils (loose material, such as clay and sand) and soft weathered rock formations (such as soft sand stone and lime stone). There are many areas around the world where it can effectively provide water for drinking and for irrigation to un-served rural populations at a fraction of the cost of conventional drilling. Manual drilling is practiced in Bangladesh, but also in neighbouring countries such as India, Pakistan and Nepal and millions of wells have been drilled, often using sludging or percussion methods. The tools and equipment are simple and can be purchased locally and fabricated in workshops. Small enterprises and local mechanics often offer well drilling services to farmers and households besides other businesses they operate. It is a well-known and well established method for rural households to get access to groundwater. The unfortunate case in Bangladesh is the presence of arsenic in shallow aquifers and most wells that have been drilled manually withdraw water from this layer. Although 27 % of shallow tube wells are known to be contaminated in the national scale, in many areas more than 90% of shallow tube wells are contaminated.

When a borehole is drilled, different types of geological formations (soil layers) can be encountered. To drill through these diverse formations a range of different manual drilling techniques have been developed and are used around the world. In each case the drilling technique must (a) break or cut the formation, (b) remove the cut material (the soil) from the hole, and (c) if necessary provide support to the walls of the hole, to prevent collapse during drilling. Each drilling technique has been developed for either one or a range of specific formations (soil layers); therefore it may be possible that combinations of different drilling techniques are used to drill a single borehole. All existing drilling techniques can be divided into four main drilling principles: Hand Auger, Manual Percussion, Sludging and Jetting. Within these four main drilling principles, a wide range of variations have been developed in various countries (PRACTICA, 2010.)

3.4 Well switching

Technology information sheet	SD-04

Highlights – Well switching, the identification and utilization of safe wells, is a simple and effective way of mitigating arsenic and salt-contamination problems (amongst others). The key prerequisite of this method is the proper monitoring of deep and shallow tube wells.

Well-switching was recommended to be more systematically encouraged for Bangladesh in a Bulletin of the World Health Organization in 2002 (van Geen et al., 2002), based on a study in Araihazar upazilla. In this study it was found that, due to high spatial variability of arsenic contamination, close to 90% of the inhabitants lived within 100 m of an arsenic-safe well. In 2004, Bangladesh issued a National Policy for Arsenic Mitigation (NPAM), where well-switching was recognized as a viable option in the sense that alternative water supply was not proposed for villages where <40% of tube wells were unsafe (Ahmed et al., 2006). The well-switching campaign had resulted in 29% of the population that was initially exposed (estimated to be 28 to 35 million) had switched wells in 2006 (see Figure ; Ahmed et al., 2006). In a UNICEF update (2008) it was reported that "about 70% of households in Bangladesh who have heard of the arsenic report are taking some action to avoid arsenic – most commonly by collecting water from a tube-well known to be safe".

However, for safe well-switching it is key that solid monitoring of tube wells is practiced throughout the country. A household drinking water survey in Singair upazilla of Bangladesh (6646 household) shows that an alarming 80% of the wells installed since the national testing campaign (2001-2004) were untested (George et al., 2012). And less than 13% of the households with untested wells knew where an arsenic-safe well was located near their home. This finding is supported by a household survey in Araihazar upazilla (Balasubramanya et al., 2013), where 22% of households did not recall test results five years after (in 2008). Nevertheless, in this study it was also found that the impact of arsenic information on switching behavior did not erode, as new switching of households with unsafe wells had doubled by 2008.

Visualization of arsenic contamination with a low-cost rapid screening tool can aid in consumer awareness and behavior change. In a recent publication (Biswas et al., 2012), the use of coloring (painting) tube well platforms to identify arsenic contamination was proposed. The results showed that with 84% certainty a red colored platform (i.e., iron-containing) indicates an arsenic unsafe tube well, compared to theWHO drinking water guideline of 10 µg/L.

Bennear et al. (2013) conducted a trial in rural Bangladesh to examine how well-switching behavior was affected by two campaign messages: (A) status quo message of safe/unsafe wells (e.g., below or above 50 µg/L standard) and (B) emphasis message, highlighting the benefits of switching to a lower arsenic well. It was concluded that while the safe/unsafe message may discourage health-beneficial switches within a safety class (e.g., from 200 to 100 µg/L), there was no empirical evidence found that the emphasis message did better.

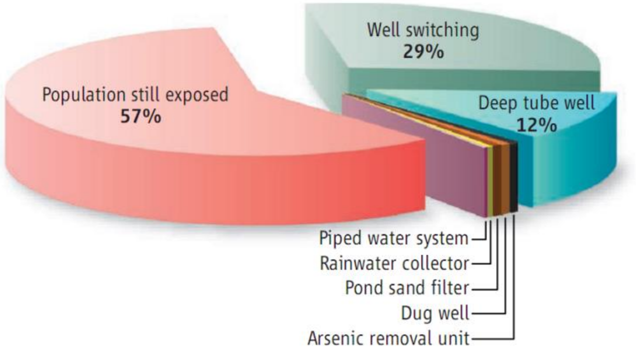

Figure 6 Impact of arsenic mitigation in Bangladesh, including well-switching (Ahmed et al., 2006)

3.5 Piped water supply schemes

Technology information sheet	CO-01

Highlights – At present, rural piped water supply schemes operate at levels that are close to the break-even point. Supported by subsidies for the hardcore poor, these methods are efficient water supply options in areas where contamination-free water does not exist in the vicinity of the beneficiaries. They can be designed with or without a treatment stage. The relatively high technical level requires professional implementation and donor-support.

3.5.1.1 The importance of piped water schemes

Choices to obtain safe drinking water may be strongly restricted in some of the regions of Bangladesh. As an example, the groundwater in the south-west of Kulna exhibits high salinity concentrations (to a depth of ~300 m) and local arsenic-contaminations (Tuinhof, 2013). The localization of safe drinking water is a challenge is such areas. As HWTS methods may not offer sufficient protection against exposure, a more reliable solution can be found in the form of small piped distribution networks. This method not only offers a more comfortable way of water provision to users, but can also contribute to easier monitoring of safe water access. As these centralized systems offer one source to distribute, monitoring the output of the source or the treatment plant may be sufficient in ensuring arsenic-free water to the end users (BAMWSP, 2007). The safety may be limited if considered that a significant fraction of users also utilizes alternative sources in the form of shallow tube or dug wells (BWSPP, 2011). Piped water methods belong to some of the most promising water supply solutions. This is partly because of their capacity to safely remove contaminations. Also, where population densities are moderate to high, they are – theoretically – a more cost-effective solution than decentralized methods. Especially because of the perceived comfortable access, strong user preference is reported for this method (BWSPP, 2011; BAMWSP, 2007).

In such a context, arsenic mitigation can be achieved in one of the two basic scenarios:

- delivery of water from contamination-free, safe aquifers, or

- delivery of treated water from arsenic- or salt-contaminated aquifers.

The first option needs to utilize safe deep aquifers in the vicinity of the intended user group and its key function is to reduce fetching distance and increase the utilization rate of a safe deep tube well for the general public. The second option is less dependent on location, but it requires the integration of arsenic- or salt-removal processes or treatment plant in order to offer safe water to the users. Ideally, both systems integrate a basic disinfection stage to ensure safe water at the point of use. Typical levels of delivery may include

- a public standpost for community use,
- public or yard-tap type connection at a shared household-level (2-5 households),
- yard-tap per household,
- in-house connection with one or multiple taps.

3.5.1.2 Municipal piped water systems

Bangladesh has a growing level of experience for two areas of piped water systems (BAMWSP, 2007). Just as most developing countries in the past, Bangladesh also engaged in the development of pourashava (municipal) systems. These systems strongly resemble 'conventional', western-type piped water treatment and distribution networks. City-wide distributions systems convey water that is treated in large-scale treatment facilities. A survey indicated that 100 out of the viewed 250 municipalities contain such piped networks. The coverage of existing pourashava piped systems is much higher than in case of counterparts reported from other developing regions (BWSPP, 2011). The Bangladeshi networks are indicated to supply 30-60% of the local population. An important limitation to these systems is that they manage to supply water only in parts of the day. The report confirms that daily supply in the surveyed municipalities was limited to 3-12 hours, necessitating household water storage to meet user needs. The complexity of these relatively high-tech centralized systems can be illustrated by the BWSPP project plan where several new systems were planned to be implemented nationwide. As the planning and financing for the new urban piped systems proved too optimistic, the plans were later restricted to the upgrading of existing initiatives. Despite the above difficulties, a strong preference for the systems was measured by World Bank surveys (BWSPP, 2011).

3.5.1.3 Current and novel rural piped water concepts

For rural or low-income urban applications, adjusted low-cost systems are indicated to be relevant. Currently applied rural systems originate mainly from the small-scale rural piped water supply scheme developed by the World Bank's BAMWSP in 1998. This initiative made use of a (then novel) cost-sharing system for the implementation. The basic element of cost-sharing implied a 10-40-50% distribution of implementation costs amongst the intended user group, the implementing company and the supporting program (BAMWSP, 2007). The constructed network would remain in the possession of the municipality, but – in return for the investment – the implementing company received the rights of management and exploitation a duration of 15 years. The initial perception of successful construction prompted the successor World Bank programme (BWSPP) to plan dissemination of this concept nationwide. The initial expectations in this programme proved so overoptimistic that such plans were largely cancelled. Ultimately, only 21 pilot, cost-sharing schemes were built instead of the planned 300. In 2003, about 100 rural piped water supply systems existed (some designed for multiple use), mostly built under the management of DPHE. The latest initiative of the World Bank and the Government of Bangladesh plans with the implementation of 125 such rural systems (BWRSS, 2013). Twenty-five of these have been reportedly initiated by the end of 2013.

Contributing to a more resilient application of rural piped water supply systems, a current research (PRACTICA, *unpublished*) views alternative low-cost, centralized systems adapted from the piped water supply scheme described by Mara and Alabaster (2008). This scheme suggests that piped water schemes can be converted into a more affordable option by offering water access through condominial (shallow) pipelines to groups of households instead of individual ones. In this scenario, the implementing organization develops the main water pipeline until the borders of household group areas. The household groups choose the level of water delivery (public standpost, yard-tap or in-house connections) and complete the side pipelines themselves (under professional guidance). Through their established representative organs (the so-called consumer cooperatives), they can optimally choose the level of connection and the related water costs themselves. As a result, piped water schemes can be implemented at a strongly reduced cost and at flexible connection levels (Mara and Alabaster, 2008). Melo (2005) cites an about 75% reduction in implementation and connection costs for such a system in Brazil. This cost reduction is achieved partly because of the shorter pipeline network and partly because of the shallow, condominial pipe laying method (~400mm below ground) applied. If added, that local capacity is expected to be sufficient for the financial management of these systems, then the adjusted method may prove useful for rural municipalities in severely contaminated areas of Bangladesh.

3.5.1.4 The potential of piped water systems in the delivery of safe water

BRAC WASH I programme information on piped networks reinforces that rural piped water networks can be successfully applied. A key feature to success is reportedly the quality of the local water management committees that are responsible for the operation of piped networks. With good management, maintenance costs are sustainably covered from the regularly collected water fees.

As a result of this (expected) eligibility, there is a growing body of knowledge in these systems in Bangladesh. This is partly the result of past initiatives, where World Bank initiatives put much emphasis on building institutional capacity in cooperation with national-level Bangladeshi institutes. At the current level of progress, the existing piped water initiatives are being improved under the guidance of DPHE and daughter institutes (among others) and it is expected that more piped systems will be implemented especially in the rural context. As Bangladesh-based knowledge is accumulating at these institutes, it is expected that piped systems will increasingly offer a resilient solution for arsenic- or salt-contaminated areas and even beyond it.

The optimal utilization of available knowledge is expected to overcome the considerable challenges of piped systems. The requirements of capacity building and investment within small communities still need to be addressed. Although cost recovery is often perceived as the limiting factor, reports indicate that management quality (delivery of services) and a realistic implementation process may be equally decisive for optimal functioning.

4 Treatment of arsenic- or salt-contaminated groundwater

Technology information sheet	TR-01 Chemical oxidation TR-02 Photo-catalytic oxidation TR-03 Conventional coagulation and filtration TR-04 Electrocoagulation TR-05 Iron- or aluminium-based adsorption TR-06 Zerovalent iron adsorption TR-07 Membrane-based removal TR-08 Bioremediation TR-09 Phytofiltration TR-10 Permeable reactive barriers TR-11 Subsurface arsenic removal

Arsenic and salt-removal from groundwater is a complex task. Many aspects have to be taken into account, and the most important ones have been already introduced in Section 2.3.3. In the following paragraphs, conventional as well as emerging technologies for arsenic and to some extent salt removal will be discussed, categorizing the various processes accordingly to their remediation principle. When applicable, available household applications (i.e., household water treatment and storage (HWTS)) operating with such remediation principles are mentioned.

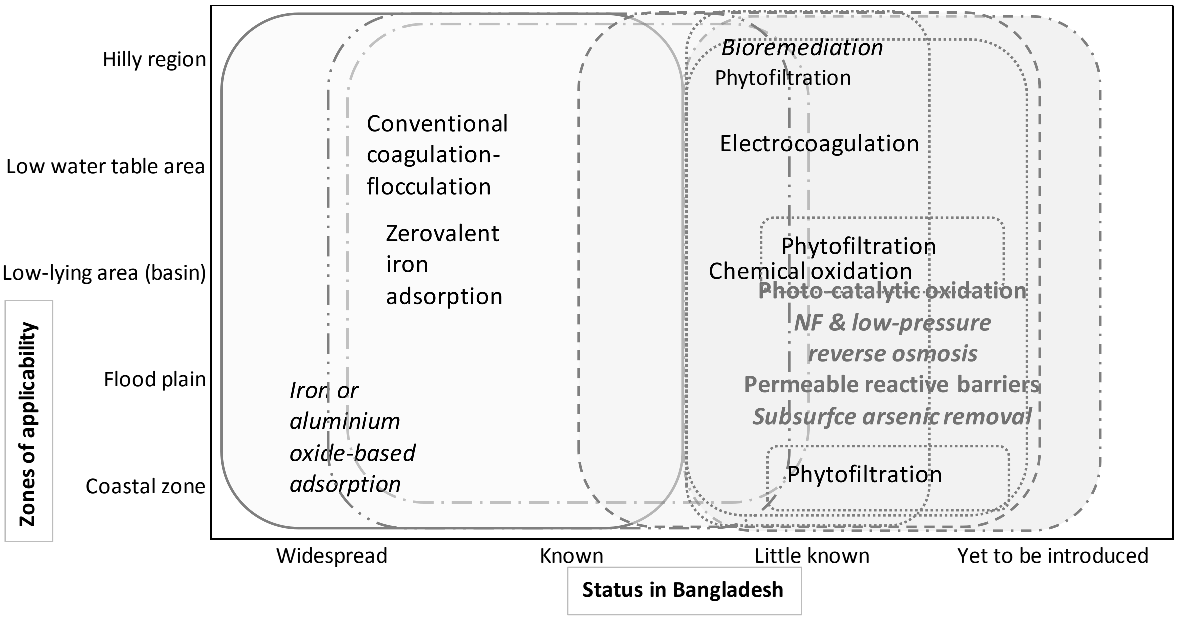

Figure 8 (Potential) use and experience of the identified arsenic- and salt-removing treatment methods in Bangladesh

Conventional technologies include preoxidation, precipitation, coagulation and flocculation, adsorption and ion exchange, and – if a more advanced category can be included – membrane filtration. Alternative methods like bioremediation, electrochemical treatments, and in-situ remediation are also used in the removal of arsenic. Figure 8 shows that efficient and, in some cases, well known methods for arsenic removal exist. The identification of relevant (affordable) desalination methods is more challenging, unfortunaltely not only in Bangladesh, but globally.

4.1 Oxidation of Arsenite

Most As removal technologies are (more) efficient when the element is in the pentavalent state, because it is present in the form of oxianions, mainly $H_2AsO_4^-$ and $HAsO_4^{-2}$, at normal drinking water pH, while the trivalent form is uncharged at pH below 9.2 (H_3AsO_3). Because of this, many arsenic remediation methods use an oxidation step as pre-treatment to other processes. However, oxidation without help of other physical or chemical treatment processes does not remove arsenic from water.

4.1.1 Chemical Oxidation

Technology information sheet	TR-01 TR-02

Highlights – This method oxidizes arsenic(III) in order to improve its removal at subsequent treatment steps. Oxidants can also limit waterborne diseases by inactivating pathogenic organisms, remove taste and odor causing compounds, and oxidize organic matter. The continuous need for chemicals may reduce its relevance in remote locations. Management requires experience as dosing depends on water characteristics. In Bangladesh, this pre-treatment has been widely applied at both household and community level.

Oxidation of As(III) to As(V) species via simple aeration is relatively slow and inefficient (Pettine and Millero (2000)). Therefore, chemicals including gaseous chlorine, hypochlorite, ozone, permanganate, hydrogen peroxide, manganese oxides and Fenton's reagent (H_2O_2/Fe^{2+}) can be employed to accelerate oxidation (Pirnie (2000)). Chlorine is a rapid and effective oxidant, but it may also react with organic matter, producing toxic and carcinogenic trihalomethanes and other disinfection by-products (Richardson et al. (2007)). Potassium permanganate effectively oxidizes arsenite, and it is a widely available, inexpensive reagent and thus suitable for developing countries.

The following reactions describe oxidation by oxygen, hypochloride, and permanganate (Visoottiviseth and Ahmed (2008)):

$$H_3AsO_3 + \frac{1}{2} O_2 \rightarrow H_2AsO_4^- + 2H^+ \quad (1)$$

$$H_3AsO_3 + HClO \rightarrow HAsO_4^- + Cl^- + 3H^+ \quad (2)$$

$$H_3AsO_3 + 2\ KMnO_4 \rightarrow 3\ HAsO_4^- + 2MnO_2^+ + 2\ K^+ + 4\ H^+ + H_2O \quad (3)$$

Hydrogen peroxide can also be an effective oxidant if the raw water contains dissolved iron, which often occurs in conjunction with arsenic contamination, allowing the occurrence of Fenton reactions generating reactive oxygen species (Hug and Leupin (2003)):

$$Fe(II) + H_2O_2 \rightarrow Fe(III) + {}^{\bullet}OH + OH^- \quad (4)$$

4.1.1.1.1.1.1.1.1 $Fe^{II}OH^{+} + H_2O_2 \rightarrow Fe^{III}OH^{2+} + {}^{\bullet}OH + OH^{-}$ (5)

$Fe^{II}CO_3 + H_2O_2 \rightarrow Fe^{III}CO_3^{+} + {}^{\bullet}OH + OH^{-}$ (6)

However, at household or small community level the storage and handling of concentrated chemical reagents always represent some risks.

4.1.2 Oxidation via Ultraviolet Radiation

Bissen et al. (2001) observed no oxidation in a 1 mg/L As(III) solution after one week in dark oxygenated aqueous solutions, while irradiation with a solar simulator produced 54% of As(III) oxidation in 45 min. The authors did not state the final reason of the oxidation acceleration, hypothesizing possible contaminants at trace levels or emission of the lamp at wavelength below 280 nm, where As(III) presents some absorption, or even temperature change. However, As(III) oxidation via direct UV illumination has low efficiency to guarantee its application in As removal.

Cheap technologies based on the use of light, abundant in many regions where, at the same time, the problem of arsenic is dramatic, can be adapted for arsenic removal. The use of solar or artificial light and dissolved iron has been the object of several studies in the last decades (i.e. Kocar and Inskeep (2003); Hug and Leupin (2003); Hug et al. (1997); Gabriela García et al. (2004)), especially to facilitate oxidation of As(III) to As(V).

4.1.3 New Developments: Advanced Oxidation Technologies

Addition of H_2O_2 to the UV system triggers As(III) oxidation through H_2O_2 photolysis, which generates ${}^{\bullet}OH$ radicals, powerful oxidants. The photolysis reaction is effective only under irradiation with wavelengths lower than 300 nm (Litter et al. (2010)).

Accordingly to Kocar and Inskeep (2003), in case dissolved organic matter is present in natural waters, H_2O_2 is produced by photochemical reactions by the action of solar light. The photooxydation rate of As(III) increases linearly with the concentration of dissolved organic matter in water (Buschmann et al. (2005)). The effect is more relevant in presence of Fe(III) which, after charge-transfer photochemical reactions, leads to the formation of Fe(II), promoting Fenton reactions and thus rapid As(III) oxidation (Hug et al. (2001)).

Based on these concepts, the SORAS (solar oxidation and removal of arsenic) method was developed as a simple process designed to provide As-free drinking water to population of very low levels of income (see Figure 7). Since its introduction (Wegelin et al. (2000)) it has been adopted with partial success to remove arsenic from groundwater for individual consumption in Argentina, Bangladesh, and India (Emett and Khoe (2001)). The raw water is filled in transparent PET bottles and exposed to sunlight for several hours. Citrate, added to the raw water in the form of lemon juice, reacts with Fe(II) present in the natural raw water or added from an external source. As a result, Fe(III)-(hydr)oxides are formed through a series of complex reactions that involve highly oxidizing radicals (Gabriela García et al. (2004)). As(III) is stabilized alongside with the iron, and the resulting As(V) is strongly adsorbed or incorporated into the precipitates. Clear water is obtained by subsequent decantation and/or filtration. The results from Gabriela García et al. (2004) state that the underlying chemistry of the process is very complex, and the efficiency is affected often in unpredictable ways by changes in the chemical matrix, or by changes in the operational conditions. A study from the Department of Sanitary Engineering of All India Institute of Hygiene and Public Health (AIIH&PH), West Bengal (India) confirmed the efficacy of the SORAS system with about 90% of As removal. The method is applicable if the iron concentration in the ground water is above the permissible level so as to adsorb the As(V) from water.

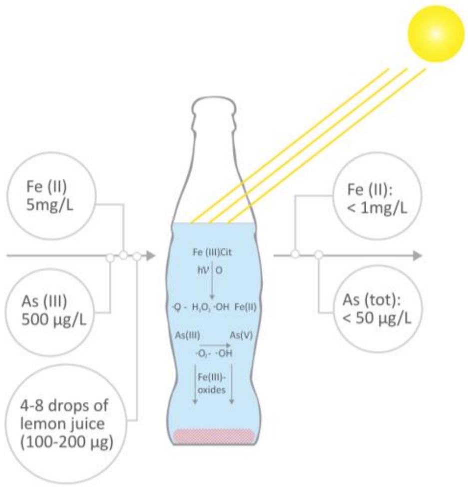

Figure 7 Operation of the SORAS process

Photocatalytic methods using TiO_2 as photocatalyst, followed by iron addition, is another recently developed, low-cost technology, suitable for As removal from water. PET plastic bottles impregnated with TiO_2 (Meichtry et al. (2007)) were used to remove As from well waters in Argentina (initial As concentration: 500-1800 µg/L, neutral pH). More than 94% removal of As(III) and As(V) was obtained when the bottles were exposed to artificial UV light in the presence of Fe(III). Fostier et al. (2008) obtained similar results with synthetic water under solar irradiation. Zhang and Itoh (2006) also used photocatalytic oxidation of arsenite and removal of the generated arsenate using a mixture of slag iron oxide and TiO_2 adsorbent. The 100 mg/L arsenite solution was completely oxidized within 3 h, but the maximum removal percentage of the generated arsenate did not reach 80%.

4.2 Precipitation, Coagulation, and Filtration Technologies

Technology information sheet	TR-03 TR-04

4.2.1 Conventional coagulation and filtration

Technology information sheet	TR-03

Highlights – In case of a low iron content, arsenic is removed by adsorption onto flocs formed after the dosage of a coagulant. Other metals and some dissolved contaminants (e.g., natural organic matter, inorganics) are removed to a lesser extent. The continuous need for chemicals may reduce its relevance in remote locations. Pre-oxidation is typically necessary, and a subsequent filtration of the flocs and a post-disinfection step is required for safe drinking water. It has been applied at both household and community level in Bangladesh with varying efficiency.

Precipitation of sparingly soluble arsenical inorganic compounds has been proposed as arsenic removal process. As(III) sulfide, calcium arsenate and ferric arsenate are among the species which present lower solubility. At the addition of calcium, magnesium, manganese (II) or iron (III) salts to As(V) solutions, As-containing solids are obtained that can be removed through sedimentation or filtration. Nevertheless, such method is normally not implemented due to the high sludge production and consequent difficulty in managing its disposal. Additionally, the stability of the different metal arsenates obtained after precipitation is strongly dependent on their nature, pH, and other variables, so that the aqueous solutions in equilibrium with the metal arsenates present often extremely high arsenic concentrations (Bothe Jr and Brown (1999); Ravenscroft et al. (2009)). Moreover, the technology requires training and discipline due to the frequent use of multiple chemicals.

On the other hand, arsenic removal by coagulation and filtration has been successfully applied for decades and constituted a solution for the problem of arsenic for both communities and small cities. The coagulation-filtration technology is simple, only common chemicals are used, installation costs are small and it can be easily applied to large water volumes. Arsenic is removed in the pentavalent form, which adsorbs onto coagulated flocs and can be then removed by filtration. Thus, As(III) has to be previously oxidized, as described previously. The most used coagulants are aluminum sulfate ($Al_2(SO_4)_3$), iron chloride ($FeCl_3$), ferric sulfate ($Fe_2(SO_4)_3$), and ferrous sulfate (FeSO4) (Pettine and Millero (2000); Visoottiviseth and Ahmed (2008)), iron salts being generally better removal agents and more efficient in a wider pH range (Ahmed and Rahaman (2000)). The dimensions of the flocs are important when sludge disposal is considered, with $FeCl_3$ generating relatively large flocs, while smaller ones are formed with $FeSO_4$ (Pirnie , 2000;Ravenscroft, 2009). The presence of phosphates or silicates in the contaminated water reduces the efficiency of arsenic removal. The usual range of coagulant dosage is between 5 and 50 mg/L. The amount of coagulant can be significantly reduced by the addition of polymers or colloidal clays during the mixing (Cheng et al. (1994)).

Filtration is a necessary last treatment step. Without filtration, arsenate removal is around 30%, but e.g. using a 0.1 or 1.0 mm filter, arsenate removal improves to >95% (Fields et al. (2000); Hering et al. (1996); Chwirka et al. (2000); Jekel and Seith (2000); Madiec et al. (2000); Sancha (2000)). Coagulation has also been used as pretreatment for microfiltration (Chwirka et al. (2004); Ćurko et al. (2011)). As already mentioned, relatively large volumes of As-containing sludges are formed, typically disposed off in landfills, and being a potential source of recontamination (see section 4.7).

For simultaneous As-Fe removal, Bordoloi et al. (2013) proposed a three-step treatment process involving $NaHCO_3$ (for mild alkaline pH-conditioning), $KMnO_4$(for oxidation of both As(III) and Fe(II)) itself precipitating as insoluble MnO_2 under the pH condition, and $FeCl_3$(for coagulation). The treated water was filtered in a sand-gravel filter after a residence time of 1–2 h. Laboratory optimization and field trials in Assam (India) were performed. Simultaneous removals of arsenic from initial 0.1–0.5 mg/L to about 5 µg/L and iron from initial 0.3–5.0 mg/L to less than 0.1 mg/L were achieved along with a final pH between 7.0 and 7.5 after a residence time of 1 h. The process also removed other heavy metals, if present, without leaving any additional toxic residue. It is estimated that a household system would generate approximately 36–50 g of solid sludge per year, which would contain mainly ferrihydrite with adsorbed arsenate. A toxicity characteristic leaching procedure (TCLP) (EPA (1992)) was performed on the solid sludge which resulted not toxic. The estimated recurring cost was USD 0.16 per m^3 of purified water.

4.2.2 Lime Softening

Highlights– Removal by adsorption. Lime is cheap and easy to obtain. In Bangladesh, not considered an efficient way to remove arsenic alone, if not in combination with high level of water hardness.

As an alternative for coagulation, in specific situations, lime softening can be used. In the presence of water and carbonic acid, lime forms calcium carbonate, and adsorbs arsenic. If needed, the formed flocs can be settled afterwards with a coagulation step. The method is to efficient to treat water with high hardness. However, a pre-oxidizing step for As(III) oxidation is required. The produced water normally presents a high pH, and an acidification step is required. Additionally, the high coagulant dosage needed and the relatively low removal efficiencies often make a secondary treatment mandatory (Kartinen Jr and Martin (1995); Pirnie (2000); Fields et al. (2000); Ravenscroft et al. (2009)).

4.2.3 Household Water Treatment and Safe Storage Solutions based on Precipitation, Coagulation, and Filtration Technologies

In HWTS, frequently are found solutions based on oxidation and coagulation-flocculation processes by dosing chemicals such as permanganate, sodium hypochlorite, iron or aluminum sulphate (DPHE-Danida BTU; BUET modified BTU; 2-Kolshi filter; ALUFLOC; Star filter), or atmospheric oxygen (Asia Arsenic Network filter, based on Roberts et al. (2004) (Table 5). Note, that only the most probable practical solutions are described in the following sections.

- **ALUFLOC**

The Panamerican Center of Sanitary Engineering and Environmental Sciences-Panamerican Health Organization (CEPIS-PAHO) developed a household scale, low-cost As removal methodology, using a product called ALUFLOC, which is a mixture of an oxidant (hypochlorite), activated clays (As adsorbents and ion exchangers) and a coagulant ($Al_2(SO_4)_3$ or $FeCl_3$) (Bedolla et al. (1999)). Coagulation produced iron and aluminum hydroxide-precipitates. Up to 98% of the dissolved As was removed from an initial concentration of 1g/L. The methodology involved different processes whose individual importance strongly varies with water chemistry (e.g. the presence and concentration of competing ions for sorption sites, pH and Eh). The cost of the technology is estimated at USD 0.15 per 20 L treated, given the assumption of production at an industrial level. Validation experiments of the technology on the specific water composition are required.

- **2-KOLSHI FILTER**

The 2-Kolshi filter is an arsenic removal method relying on a first coagulation process in an upper bucket with iron sulphate and sodium hypochlorite, followed by a filtration in a ceramic filter. Oxidation of As(III) to As(V) is achieved by manual stirring, As(V) then co-precipitates with iron chloride and ash, and then the water is filtered to remove the formed particles. As-removal rates are reported to be between 80% and 90%. The needed chemicals ($FeSO_4$, NaClO and ash) are not easily available at local markets and need to be shipped from main commercial centers (Ngai et al. (2004)).

- **BUCKET TREATMENT UNIT (BDPHE-DANIDA RESEARCH PROJECT)**

The Bucket Treatment Unit (BTU), developed from the DPHE-Danida Research Project, uses the principles of oxidation, coagulation, coprecipitation, and adsorption, followed by a filtration step. This unit consists of two 20 L buckets placed one above the other. The BTU units utilize chemical doses of 200 mg/L aluminum sulfate and 2 mg/L potassium permanganate, supplied in crushed powder form for water treatment. Chemicals are manually mixed with arsenic contaminated water in the upper bucket. After 1-2 h for settling, water from the top bucket is drained into the lower bucket via a plastic pipe, then through a sand filter installed in the lower bucket. Under rural operating conditions in Bangladesh, units often failed to remove arsenic to the target level (0.05 mg/L), also resulting in too high concentrations of aluminum and manganese in the treated water. Poor mixing and variable water quality (particularly pH) appeared to cause the poor performance (Sutherland et al. (2002)).

Table 5 Potential HWTS devices using precipitation, coagulation and filtration

Method Physical-chemical treatment	**Removal Efficiency**	**Production**	**Lifespan**	**Costs**
Alufloc Oxidation, activated clays (adsorption + IX), Coagulation-Flocculation Sedimentation	70-98%	20 L/h	-	USD 0.15 per 20 L treated
2-Kolshi Oxidation Coagulation-Flocculation Filtration	90% As 99% m.o.	3-5 L/h	-	USD 10/USD10-20**
BTU Oxidation Coagulation-Flocculation Sedimentation Filtration	~60% As	20 L/h	-	USD 10/USD10-15
Modified BTU Oxidation Coagulation-Flocculation Sedimentation Filtration	?	20 L/h	-	USD 10/USD10-15**
Star Enhanced coagulation and coprecipitation (ferrous suphate), and sand filtration	> 90%	169 L/d	-	USD 25/USD1.80**
Arsenic Asia Network* *Manual aeration* *Oxidation* *Co-precipitation* *Filtration*	*70-80% As*	*20L/6h*	-	*USD 15-20 capital cost*
Sources: Johnston and Heijnen (2002); BETV-SAM (2003); WBWSP (2005); Delawar (2006); CAWST (2009); Visoottiviseth and Ahmed (2008); Canyelles (2004); Sutherland et al. (2001); Sutherland et al. (2002); IGRAC (2007); EPA (2007); AWWA (2000); Hunter (2009)				

**Device in italic is not included in detail in the main text.*

***The first price signifies the capital cost needed for the purchase of the filter; the second price indicates the operational costs per annum for one family unit (roughly translating to the needs of five people).*

MODIFIED BTU (BANGLADESH UNIVERSITY OF ENGINEERING AND TECHNOLOGY)

Bangladesh University of Engineering and Technology (BUET) modified the BTU by using 100 mg/L ferric chloride and 1.4 mg/L potassium permanganate. The treatment ensured a removal efficiency above 90%, with final concentrations of As never exceeding 37 µg/L compared to concentrations in the tubewell water up to 640 µg/L (Visoottiviseth and Ahmed (2008)). The BUET-modified BTU is depicted in Figure 8.

The modified BTUs are also effective in removing iron, manganese, phosphate, and silica. Initially, fecal coliform bacteria were found in treated waste, probably derived from contact with contaminated human hands. This recontamination was eliminated by adding bleaching powder to the chemical packet used in the BTU. The BTU is a promising technology for economic arsenic removal at household level. It can be locally built using available materials and is effective if operated properly.

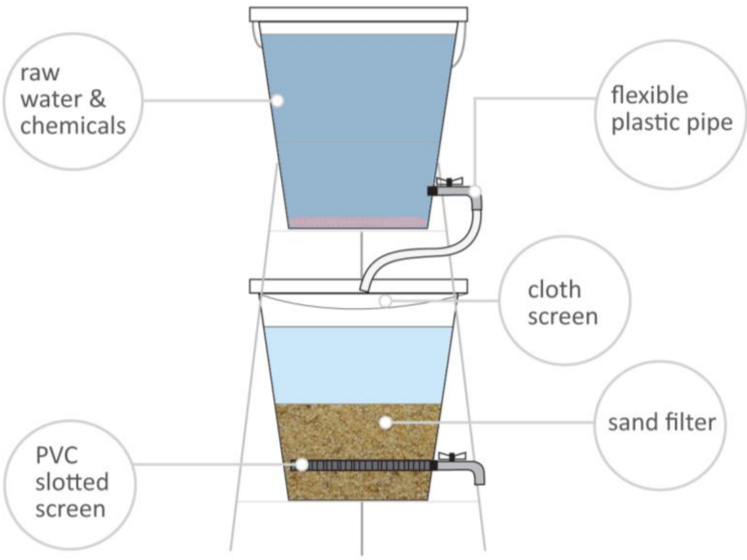

Figure 8 Modified Bucket Treatment Unit (BTU)

- **STAR FILTER**

The Star Filter developed by the Stevens Institute, USA is based on a two buckets system, one to dose the chemicals (iron coagulant and hypochloride supplied in packets) and the other to separate the flocs by sedimentation and filtration. The second bucket has an inner bucket with side slits to help sedimentation and retain the filtration sand bed. The flocs quickly clog the sand bed which needs to be washed twice a week. An assessment by Sutherland et al. (2002) proved the effectiveness in reducing arsenic levels to less than 50 µg/L for more than 90% of the tested samples. The initial cost of the filter is USD 25. The yearly cost is estimated around USD 1.80 for a family of five.

4.2.4 New Developments: Electrocoagulation

Technology information sheet	TR-04

Highlights –Simultaneous removal of several contaminations without the use of chemicals. It requires an additional filtration or settling post-treatment and a disinfection unit. Theoretically, lack of regular supply and broad purification range makes it robust for remote, centralized applications (like for rural piped water supply schemes).

Among the emerging technologies investigated for arsenic removal in the last decade, electro-coagulation (EC) attracted great interest among the scientific community (i.e. Li et al. (2014); Li et al. (2012); Zhao et al. (2010); Wan et al. (2011); Lakshmipathiraj et al. (2010); Del Ángel et al. (2014)).

The process involves electrochemical phenomena that simultaneously removes heavy metals, suspended solids, emulsified solids and other contaminants from water using electricity with metal plates/electrodes instead of chemicals (Ali et al. (2011)). EC is a technique where no coagulants are added, thus, reducing the amount of sludge (Cenkin and Belevtsev (1985)). Electrocoagulation for arsenic has been achieved by iron and aluminum electrodes (Li et al. (2014); Ucar et al. (2013); Kobya et al. (2013); Kobya et al. (2011); Mólgora et al. (2013); Kumar et al. (2004); Dolo and Goel (2010)), with iron representing the most efficient choice (Ali et al. (2011)). However, some authors also reported the use of titanium, copper and zinc electrodes (Kumar et al. (2004); Maldonado-Reyes et al. (2007)). The electrocoagulation process can be divided into three parts (see Figure 9): (i) electrolytic oxidation of the sacrificial anode and, thus, formation of coagulants, (ii) destabilization of the contaminants, particulate suspension, and breaking of emulsion and (iii) aggregation of the destabilized particles to form flocs. Subsequently, sedimentation of the flocs is slow, but it can be accelerated by dosing 2 mg/l of Al^{3+} (Li et al. (2014)). Alternatively, flocs can be removed by filtration using a sand filter or microfiltration membranes.

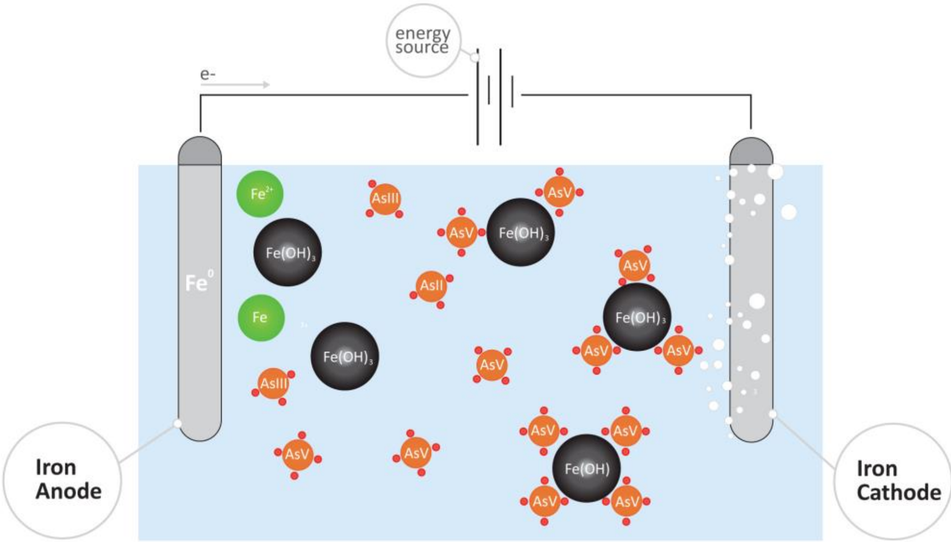

Figure 9 Operation of a Fe-Fe electrocoagulation system. Iron (Fe) from the anode dissolves into solution, forming rust. The rust forms complexes with arsenic in solution through adsorption to the rust surface, or precipitation into a new iron-arsenic solid. The arsenic-laden rust complexes are then filtered or settled out of the water (Amrose et al. (2013)

Arsenic-removal efficiencies are generally above 90%, and optimization can lead to a reduction of As concentration from 100-500 µg/L to less than 10 µg/L. An increase of the pH between pH 6 and 10 brought to better efficiencies in As-removal for Fe-Fe electrodes (Deniel et al. (2008)), while no significant effect was observed for Al-Al electrodes (Gomes et al. (2007)). Processing time diminishes when a higher current density is applied (Maldonado-Reyes et al. (2007)). Amrose et al. (2013) successfully mitigated arsenic concentrations as high as 760 µg/L with charge loading 150 – 455 C/L to below WHO recommended levels using both batch and continuous flow reactors, even in presence of phosphate and silicate which are both known to hinder arsenic removal performance of EC (Wan et al. (2011)). In Li et al. (2014) iron scrap, an abundant byproduct from iron planing machines, exhibited the same capacity as iron plates for As removal during electrolysis, further reducing the material cost of EC.

4.3 Adsorption and Ion Exchange Technologies

Technology information sheet	TR-05 TR-06

Adsorption implies the removal of a contaminant from water by attachment onto the surface of a porous solid adsorbent. Adsorption involves the use of granular adsorptive media for the selective removal of arsenic from water with or without pH adjustment and with or without spent media regeneration. The removal mechanism of arsenic onto solid surfaces involves a combination of phenomena which include surface complexation (ligand exchange or inner-sphere complex formation), ion exchange (weak ionic attraction in the diffuse layer), and surface precipitation. Selective adsorption via biological materials, mineral oxides, activated carbons, or polymer resins, has generated increasing attention (Benjamin et al. (1996)).

A vast variety of materials has been used as adsorbents in arsenic removal (Mohan and Pittman Jr (2007)), but the most conventional technologies adopt aluminum oxides and iron oxides. Titanium dioxide (Bang et al. (2005b); Bang et al. (2011)), cerium oxide (Sun et al. (2012); Srivastava (2010); Shin-Nihon-Salt-Co.Ltd. (2000)) or manganese dioxide (Ajith et al. (2013); Chang et al. (2012);Driehaus et al. (1995)) also proved to be effective. Among others, the mechanism of As(III) oxidation and adsorption on nanosized birnessite (Mn(IV)) is noteworthy due to its high As removal (>120 mg/g) (Dias et al. (2008)), more than one order of magnitude higher than the values reported for As adsorption on other Fe–Mn-mineral materials (Deschamps et al. (2005)). Similar results were obtained by Zhang et al. (2007).

The adsorption technology is simple, does not require chemical addition, and it can be applied at both community and household levels. However, several studies raised concerns regarding the efficiency of most of the adsorption methods in lowering arsenic concentration to acceptable levels, and are recommended to treat only water presenting a low arsenic and iron content (Chaudhury et al. (2003); Driehaus et al. (1995)).

Hossain et al. (2005) evaluates the efficiency of arsenic removal plants in removing arsenic and iron from raw groundwater by adsorption, covering 18 plants from 11 national and international manufacturers installed within the Technology Park Project in an arsenic affected area of West Bengal, India. The first analysis in September 2001 (few weeks after the start of the project) found that 10 of 13 plants failed to remove arsenic below the WHO provisional guideline value (10 µg/L), while six plants could not achieve the Indian Standard value (50 µg/ L). The highest concentration of arsenic in filtered water was observed to be 364 µg/L. The 2-years' study showed that none of the plants could maintain arsenic in filtered water below the WHO provisional guideline value and only two could meet the Indian standard value (50 µg/L) throughout. Standard statistical techniques showed that even plants from the same manufacturers were not equally efficient. During the study period almost all the installations underwent minor or major modifications to improve their performance, and 15 out of 18 were no longer in use at the end of the study. Several problems were addressed in the paper, among others lack of user friendliness, insufficient maintenance, and clogging.

4.3.1 Iron Oxides-Based Adsorbents

Technology information sheet	TR-05

Highlights – Arsenic is removed by attachment onto the surface of a porous solid adsorbent. Pre-oxidation of arsenite improves efficiencies. No additional chemicals needed. Type of adsorbent affects the operational costs, but optimized systems are efficient and inexpensive. It has been applied at both household and community level in Bangladesh.

Iron oxides, oxyhydroxides and hydroxides, including amorphous hydrous ferric oxide (FeO-OH), goethite (α-FeO-OH) and hematite (α-Fe_2O3), are considered to be good adsorbents for removing both As(III) and As(V) from water (i.e., Ferguson and Gavis (1972); Roberts et al. (2004)). Amorphous Fe(O)OH has the highest adsorption capability since it has the highest surface area. Surface area is not the only criterion for high removal capacities of metal ions and other mechanisms such as ion exchange and precipitation play an important role as well. Most iron oxides are fine powders that are difficult to separate from the solution afterwards. Therefore, the EPA has proposed iron oxide-coated sand filtration as an emerging technology for arsenic removal at small water facilities (Thirunavukkarasu et al. (2003); Thirunavukkarasu et al. (2001)). Quartz sand coated with iron salts has also been used for the removal of arsenic from groundwater (Joshi and Chaudhuri (1996)). A low-cost home arsenic removal unit (material and fabrication cost: 6USD cost of medium: USD2, and regeneration cost: USD 0.15), containing 6 kg (4 L) of iron oxide-coated sand, produced between 150 and 200 bed volumes of water with As concentration below 10 µg/L in two cycles when the influent As(III) or As(V) concentration was 1.0 mg/L.

Commercially available granular iron hydroxide, GEH®, a synthetic akaganeite, also proved to be an efficient material, able to retain As(V) and As(III) (Driehaus (2002); Hering et al. (1997)). Pal Trockner (P) Ltd (India) and Sidko Limited(Bangladesh) installed several arsenic removal units based on granular iron hydroxide in India and Bangladesh. The average treatment costs is USD 0.05 per m^3 treated water, while treatment capacities are up to 150000 bed volumes.

Granular iron oxide (Bayoxide®, GFO) is another similar successful material (Uddin et al. (2008); Bang et al. (2011)).

As an alternative, iron hydroxide nanoparticles were introduced into a polymeric network of an ionic exchange resin (Zhang et al. (2008)). The materials were tested with good results in arsenic-contaminated groundwater between Bangladesh and India (Cumbal and Sengupta (2005); DeMarco et al. (2003)). These authors inserted nanoscale hydrated Fe(III) oxide (HFO) particles within the polymeric beads to overcome the unsuitability of HFO for plug flow configurations due to excessive pressure drops and poor durability. Commercially available cation and anion exchangers were used as host materials for dispersing HFO particles within the polymer phase, the latter exhibiting a much higher As removal capacity. Since hybrid anion exchanger-macroporous (HAIX-M) beads were suitable for caustic soda regeneration, their reuse for several cycles was confirmed. This technology seems interesting for As removal for (small) communities, but due to economic limitations not for household scale.

The spent sludge from the sand filters is an issue of concern due to the possibility of toxic releases after being discarded (Ford (2002); Dixit and Hering (2003); Badruzzaman (2003)). Several options were suggested or practiced for minimizing the possible risks of contaminant release from the sludge material (see section 4.7).

4.3.2 Aluminum Oxides-Based Adsorbents

Technology information sheet	TR-05

Highlights – Arsenic is removed by attachment onto the surface of a porous solid adsorbent. Also removes fluoride, selenium, silica, and NOM. Inexpensive treatment option. No additional chemicals needed, but pre-oxidation of arsenite and pH adjustment might be necessary. Frequently used in Bangladesh with high rates of success, both at household and community level.

Arsenic adsorption on activated alumina (AA) has received substantial attention. AA, prepared by thermal dehydration of aluminum hydroxide, has a high surface area and a distribution of both macro- and micropores. Granular activated alumina is a commercially available porous oxide. Within a pH range of 5-7, the adsorbent has been successfully applied reaching efficiencies higher than 95% (Pirnie (2000)). The United Nations Environmental Program agency (UNEP) classified AA adsorption among the best available technologies for As removal from water. Accordingly to Blaney et al. (2006) over 150 gravity-fed well-head community based arsenic removal units using AA are in operation in the bordering areas of West Bengal, India, and Bangladesh. As(V) sorption occurs best mostly between pH 6.0 and 8.0 where AA surfaces are positively charged. As(III) adsorption is strongly pH dependent and it exhibits a high affinity towards AA at pH 7.6 (Singh and Pant (2004)). The alumina surface is saturated very rapidly at high As concentrations, but it can be regenerated, usually with a caustic bath followed by an acid treatment (Kartinen Jr and Martin (1995)). Efficiencies are higher with As(V) than with As(III).

Kuriakose et al. (2004) removed arsenites from water with AA and iron oxide-impregnated AA. The adsorption capacity of iron oxide impregnated AA (12 mg/g) was higher than AA (7.6 mg/g).

Several inorganic-organic hybrid adsorbents bearing thiol groups could be found in literature by modifying AA with mercaptopropyl-functionalized silica, enhancing As(III) adsorption capacities. Hao et al. (2009) stated that, compared to AA, the functionalized hybrid adsorbents have decreased surface areas, pore sizes and pore volumes, and exhibited enhanced adsorption abilities for As(III). As the thiol loading increased, the uptake of As(III) increased, while the efficiency (adsorbed As(III)/–SH molar ratio) decreased. A removal percentage up to 99.7% of As(III) was achieved using 1.0 g/L adsorbent and 2 mg/L of initial As(III) concentration. The As(III) removal by the hybrid adsorbents synthesized in this study could be a direct remediation process, eliminating the need for pre-oxidation of As(III).

Conventional AA has an irregular pore size distribution , low adsorption capacities and exhibits slow kinetics (Kim et al. (2004)). An ideal adsorbent should have uniformly accessible pores, a three dimensional pore system, a high surface area, fast adsorption kinetics, and good physical and/or chemical stability. For this purpose, Kim et al. (2004) prepared a mesoprous alumina (MA) with a large surface area (307 m^2/g) and uniform pore size (3.5 nm) for arsenic removal. A sponge-like interlinked pore system was developed through a post-hydrolysis. The resulting MA was insoluble and stable at pH 3–7 and its adsorption kinetics were rapid. The maximum As(V) uptake by MA was seven times higher (121 mg of As(V)/g and 47 mg of As(III)/g) than that of conventional AA. This adsorbent's surface area did not greatly influence the adsorption capacity. The key factor is a uniform pore size. More than 85% of the adsorbed arsenic desorbed in less than 1 h using 0.05M NaOH.

4.3.3 Zerovalent Iron (ZVI)

Technology information sheet	TR-06

Highlights – Removal by adsorption. If present, waterborne viruses are removed together with arsenic. Proper aeration of the water is required for this treatment process to be effective, subsequent filtration is advisable. No additional chemicals. ZVI is an established technology for water treatment in Bangladesh, both at household and community level.

Zerovalent iron (ZVI) has been lately adopted as a new sorption medium to remove both arsenate and arsenite (Kanel et al. (2005); Leupin and Hug (2005); Su and Puls (2001)). ZVI has several advantages compared to other adsorbents. First of all, it is cheap and widely available in many forms. In addition, the intermediates formed during ZVI corrosion can oxidize As(III) to As(V), which eliminates the need of an additional oxidation, while iron corrosion produces ferric oxyhydroxides (FHO), which strongly sorb As and functions as a continuous regeneration of the filtrating media (Einschlag and Triszcz (2013); Triszcz et al. (2009); Leupin et al. (2005)) (see Figure 10). In addition, ZVI filtration was reported to remove pathogens from contaminated water (You et al. (2005).

Removal by ZVI takes mainly place by adsorption and coprecipitation onto these FHO, through a mechanism involving ZVI corrosion to Fe(II) and Fe(II)/(III) (hydr)oxides (iron rusts, magnetite, lepidocrocite, maghemite, ferrous hydroxide ($Fe(OH)_2$) and ferric hydroxide ($Fe(OH)_3$)), depending on the redox conditions and pH. Then, in the presence of dissolved O_2, reactive oxygen species are formed, leading to oxidation of reduced iron species to Fe(III). Results from basic experiments using ZVI from local iron materials, iron wool, and packing wire, as well as iron nanoparticles can be found in literature also in association with solar irradiation (Neumann et al. (2013); Cornejo et al. (2008); Hussam and Munir (2007); Nikolaidis et al. (2003); Karschunke and Jekel (2002); Farrell et al. (2001); Khan et al. (2000)) .

In Du et al. (2013) bifunctional resin-supported nanosized zero-valent iron composite was developed by combining the oxidation properties of nanosized ZVI with adsorption features of iron oxides and anion-exchange resins. Capacities for As(III) and As(V) resulted topping 120 mg/g. In order to investigate the potential performance of the material in practical use, fixed-bed column experiments with simulated waters were performed. Breaktrough of As above 10 µg/L was reached afer 2700 bed volumes. In presence of silica and phosphate, the strong competition drastically changed the performance to a less practical 400 bed volumes.

Bang et al. (2005a) showed that the adsoption of zerovalent iron filings for arsenic remediation was dramatically affected by oxygen content and pH. Arsenate removal by ZVI filings was faster than arsenite under oxic conditions. More than 99.8% of the As(V) was removed whereas 82.6% of the As(III) was removed at pH 6 after mixing for 9 h. When dissolved oxygen was removed by nitrogen purging, less than 10% of the As(III) and As(V) was removed. High dissolved oxygen content and low solution pH increased the iron corrosion rate. Thus, arsenic removal by ZVI was attributed to adsorption onto iron hydroxides generated from ZVI corrosion. Arsenic uptake by ZVI proceeded by electrochemical reduction of As(III) to insoluble As(0) and adsorption of As(III) and As(V) on surface iron hydroxides formed under anoxic conditions. The removal rates of As(V) and As(III) from water were much higher under air than under the anoxic conditions. As(V) removal was faster than As(III).

For a comprehensive review of the removal mechanisms for As and other contaminants using ZVI see Noubactep (2013).

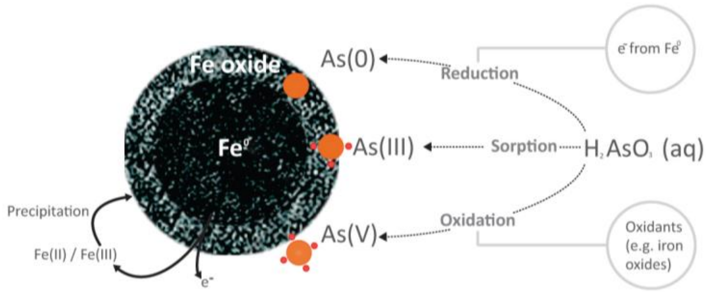

Figure 10 Processes involved in ZVI based As-mitigation

4.3.4 Ion Exchange (IX) Resins

Highlights – Removal by a physico-chemical process. Cost prohibitive for household application. Pre-oxidation is needed in case of presence of As(III). Trained personnel are required to regenerate exchange media. In Bangladesh it can find its application at (small) community level.

Synthetic anion exchange resins can be applied for As removal as well, however, ion exchange does not remove As(III) because it occurs predominantly as neutral complexes (H_3AsO_3) in water with a pH value lower than 9.0. The predominant species of As(V), $H_2AsO_4^-$ and $HAsO_4^{2-}$ are negatively charged, and thus are removable by IX. If As(III) is present, it is necessary to oxidize As(III) to As(V) before removal by IX (Ravenscroft et al. (2009); Pirnie (2000)). Commonly, resins are pretreated with hydrochloric acid or sodium chloride, to establish chloride ions at the surface, which are easily displaced by arsenic. Small-scale systems and point-of-entry systems often use ion exchange for arsenic removal because they are easy to use without sludge production.

Tetrahedron (USA) promoted an ion exchange-based arsenic removal technology in Bangladesh. In this process tubewell water is pumped or poured into a stabilizer through a sieve containing a chlorine tablet (for disinfection and As-Fe oxidation). Pump flow pulses are regularized by a stabilizing chamber which also traps precipitates. The IX column then exchanges As(V) together with sulphate and phosphate for chloride (?). Promising results were shown by Sutherland et al. (2002).

However, treatment costs are relatively high compared to other conventional treatments in large-scale systems. Arsenate removal is relatively independent of pH and effective at any influent concentration. $HAsO_4^{2-}$ is more easily exchanged than $H_2AsO_4^-$. Competing anions, especially sulfate, TDS, selenium, fluoride, and nitrate, interfere strongly and can affect run length before breakthrough.

4.3.5 Household Water Treatment and Safe Storage Solutions

Technology information sheet	TR-05 TR-06

Highlights – The potentially most applicable arsenic removal methods for household-scale purification. Applicable only where no salinity problems are present and where safe water provision cannot be achieved at a more central level. Method application requires extensive training campaigns and a strict monitoring to be effective. HWTS methods may also be less cost-effective in comparison with central solutions, when viewed for their total cost per household.

Since adsorption and IX are simple technologies and do not require chemical addition, they have been widely implemented in many household applications. These methods have been adapted for the use in downsized equipment, technically simplified or modified from their original version. In HWTS's, the main features to consider are the ease of operation, costs, and the advantage of simultaneous disinfection, As(III) oxidation and turbidity removal. The majority of the adsorption-based HWTS technologies (Table 6) targeting arsenic removal rely on iron oxides, such as cast iron (ZVI) (SONO filter), iron coated bricks/sand (Shapla and IHE filter), iron nails (Kanchan filter), or activated alumina (Alcan filter). In order to remove iron from the groundwater these filters use a bucket-style sand filter. Ion exchange resins have also been used for household arsenic removal (Read-F; Tetrahedron), in combination with a cloth and/or sand filter. In the following several examples of HWTS are discussed.

- **SHAPLA FILTER**

The Shapla filter operates based on the adsorption of arsenic onto iron-coated brick chips (treated with $FeSO_4$). It is an earthen household arsenic removal technology developed by International Development Enterprises (IDE), Bangladesh. The filter can hold up to 30 L of water. As water passes through the filter, arsenic from the water is rapidly adsorbed by the iron on the brick chips. The filter can produce up to 3000 L of arsenic-free water. Capital cost is around USD 10, and media replacement is USD 10-15 per year (CAWST (2009b)). Field tests showed arsenic removal rates around 98% (NAISU (2003)).

Table 6 Potential HWTS devices using adsorption

Method Physical-chemical treatment	**Removal Efficiency**	**Production**	**Lifespan**	**Costs**
Shapla Adsorption of iron coated brick chips	80-90% As	25-30 L/d	3-6 months	USD10/USD10-15**
Sono Surface complexation: Adsorption by oxidized iron chips and sand	90-95% As	20-30 L/h	Replace unit after 3-5 years	USD 40-50 capital cost
Kanchan Surface complexation: Adsorption by oxidized iron chips, nails and sand Filtration Biological conversion	85-95% As 90-99% Fe	24-36 L/d	10+ years with regular replacement of parts	USD 12-30/USD1-2**
Alcan Adsorption	80-85% As	100 L/h	6 months to 1 year	USD 35-50 capital cost
Read-F Adsorption	>95% As	~45L/d	2-3 years	USD 50-70 capital cost
Sidko* *Adsorption by granular $Fe(OH)_3$* *Oxidation* *Flocculation*	*65-70% As*	*~2250 L/d*	*10-15 years*	*USD 4250/USD 750***

Sources: Johnston and Heijnen (2002); BETV-SAM (2003); WBWSP (2005); Delawar (2006); CAWST (2009); Visoottiviseth and Ahmed (2008); Canyelles (2004); Sutherland et al. (2001); Sutherland et al. (2002); IGRAC (2007); EPA (2007); AWWA (2000); Hunter (2009)

**Device in italic is not included in detail in the main text.*

***The first price signifies the capital cost needed for the purchase of the filter; the second price indicates the operational costs per annum for one family unit (roughly translating to the needs of five people). One exception is the Sidko filter that is applied at small-community scale.*

- **SONO FILTER**

Hussam and Munir (2007) developed a simple and effective arsenic filter (SONO Filter) and won the gold medal from the National Academy of Engineering - Grainger Challenge Prize for Sustainability. The filter has been approved by the Bangladesh Government and about 30,000 SONO filters were distributed all over Bangladesh. The filter removes arsenic species primarily by surface complexation reactions on a specially manufactured composite iron matrix (ZVI). The filtered water meets WHO standards even after 8 years of use (Neumann et al. (2013)). Additionally, SONO filters work without any chemical treatment, and no regeneration is needed. Leaching tests (EPA (1992)) with spent composite iron showed very low remobilization of As, rendering used ZVI non-hazardous. It costs about USD 40 for 5-8 years and produces 20-30 L/h for daily drinking and cooking need of 1-2 families. Figure 11 depicts the two possible configuration of the filter.

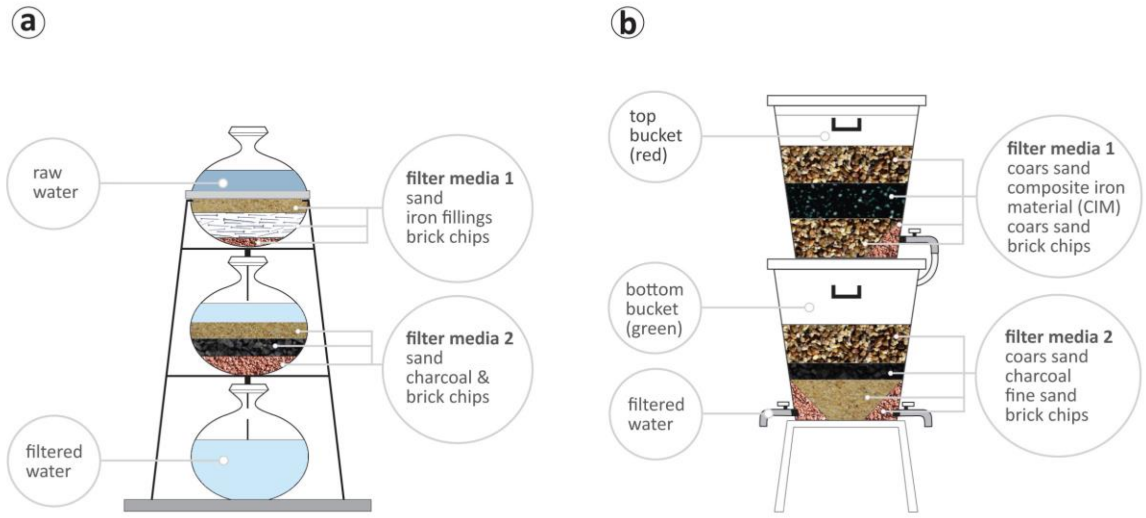

Figure 11 The SONO filters for arsenic removal from groundwater. (A) SONO 3-kalshi filter (B) SONO arsenic filter.

- **KANCHAN™ FILTER**

The Kanchan™ Arsenic Filter (KAF) (Ngai et al. (2006)) is a combination of a biosand filter with an As-removal process. It was developed by a collaboration between Massachusetts Institute of Technology (MIT), Environment & Public Health Organization (ENPHO), and Rural Water Supply and Sanitation Support Programme (RWSSSP), Nepal. A layer of rusty nails is incorporated in the diffuser basin of the filter (see Figure 12). The rust provides adsorption sites for arsenic on iron (hydr-)oxides. Pathogens such as bacteria are removed mostly by physical straining provided by the fine sand layer, by attachment to previously removed particles, by biological predation occurring in the top few centimeters of the sand, as well as by natural decay. Field tests showed an average arsenic removal efficiency of 90–93%, with >95% of the filters producing water within the Nepali guidelines of 50 ppb. The filter operates without added chemicals, and O&M is represented only by the replacement of nails (approximately every 3 years, depending on water quality).

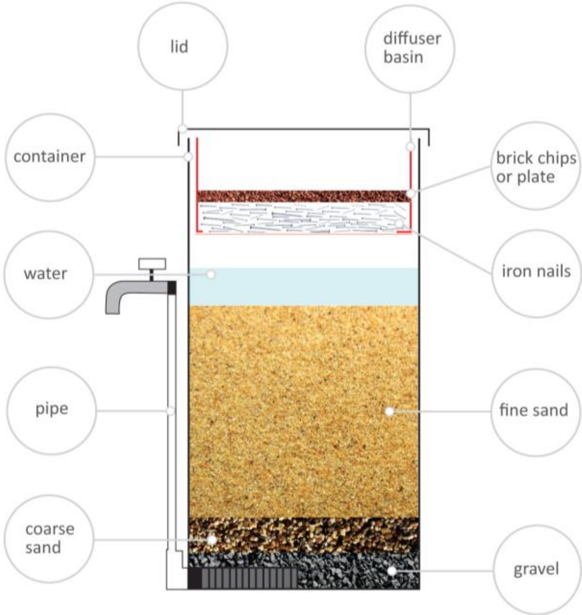

Figure 12 Major components of the KanchanTM arsenic filter (from CAWST (2009a)).

- **ALCAN FILTER**

The Alcan is a two bucket system. The buckets are in series and both filled with an enhanced activated alumina (AA) media produced by MAGC Technologies and Alcanof US. Arsenic is removed by adsorption to AA. No chemicals are needed during operation. The arsenic removal capacity of the unit might be reduced by the presence of iron and phosphate ions competing for active sites on alumina. More than 300 L per hour of As-free water can be produced (Sutherland et al. (2002)). The media has to be safely disposed after use.

- **READ-F FILTER**

Promoted by Shin Nihon Salt Co. Ltd. (Japan) and Brota Services International (Bangladesh), Read-F is a selective adsorbent which efficiently adsorbs arsenite and arsenate. The filter consists of an ethylene-vinyl alcohol copolymer (EVOH) and hydrous cerium oxide (CeO_2• nH2O) which acts as the adsorbent. No preoxidation or pH adjustment is needed. READ-F technology is commercially available in Bangladesh as a household and as a community treatment unit, both presenting a sand pre-filter to prevent bed clogging by iron precipitates. Having provided efficient arsenic removal for water treatment facilities at Ibaraki, Japan, READ-F is approved by the Japan Ministry of Health and Welfare (Visoottiviseth and Ahmed (2008)). READ-F regeneration is done by sodium hydroxide addition followed by sodium hypochloride, and water rinsing. The material contains no organic solvent or other volatile substance and spent material is not classified as hazardous. Laboratory test at BUET and field testing of the materials at four sites under the supervision of BAMWSP showed that the adsorbent is highly efficient in removing arsenic from ground water.

4.3.6 New Developments: Geological and Organic Adsorbents

- **GEOLOGICAL MATERIALS AS NATURAL ADSORBENTS**

Highlights – Arsenic removal by porous natural adsorbents. No chemicals required. Backwash of the bed by trained personnel necessary to avoid clogging. Efficiency of this technology varies widely on the choice of (preferably locally available) adsorbent. No Bangladeshi application reported.

If natural geological adsorbents (i.e. soils and sediments) are available in the area where the As contamination is present, their use can be the only option to provide safe water to very poor settlements. Their suitability for As removal from water is mainly due to adsorption, coprecipitation, and ion exchange processes involving Fe- and Al-rich minerals and clay minerals included in the soils or sediments. Such materials incude hematite (α-Fe_2O_3), goethite (α-FeO(OH)), and soils or sediments containing these minerals (e.g., laterite (Viet et al. (2002)), oxisols). Other As-sorbents tested were limestone and iron-coated zeolites. Clay minerals such as montmorillonite (and clays such as bentonite, consisting predominantly of montmorillonite) have been used in a colloidal form as absorbents.

Crushed indigenous limestone (soyatal limestone) with 41.4% CaO, with a 34% loss on ignition and trace amounts of Fe, Al, and Mn, was tested in batch and column tests for As removal from well water (around 500 mg /L of As)(Armienta et al. (2009); Romero et al. (2004)). Experiments using limestone (10 g/L in the raw water) showed 90% As removal within the first 5 min and the same particles could be used for five separate cycles.

Natural red earth (NRE) from Sri Lanka, was also used as an adsorbent to examine its retention behavior for As (III) and As (V) (Vithanage et al. (2007)). The equilibrium solid phase concentrations for As(III) and As(V) were observed as ~20 and ~12.5µg/g, respectively (Rajapaksha et al. (2011)). These studies suggested a potential for possible use of NRE in domestic water filters to remove As from water

Clay-rich soils and sediments needs to be tested for efficiency before its application in the field as adsorbents since great variation in the mineral composition can lead to different results. High concentrations of Fe and Al hydrous oxides in the materials generally leads to higher As removal efficiencies (Claesson and Fagerberg (2003)).

As result of most of the treatments based on natural geological materials, the As-loaded adsorbents could still be classified as non-toxic according to the TCLP (EPA (1992)), thus making the spent material suitable for discharge in landfills.

- **ORGANIC MATERIALS AS NATURAL ADSORBENTS**

Low-cost organic materials have been tested for their suitability to remove As from water, including cellulose, milled bones, sedges, sorghum biomass and agricultural waste material.

Haque et al. (2007) studied the suitability of sorghum biomass for As removal from aqueous solutions. The study determined two potential binding sites associated with carboxyl and hydroxyl groups. The equilibrium time for As adsorption on sorghum was 12 h. The effect of pH on As adsorption was investigated over a pH range between 2 and 10. They found a strong influence of pH with a maximum removal of As at pH 5.0. Through column experiments, it was found that for both nonimmobilized and immobilized sorghum biomass, the maximum adsorption capacities were 2.76 and 2.43 mg of As/g, respectively.

Agricultural waste materials seem to have some potential in removing arsenic from contaminated water. The main components of such materials (i.e., lignin and cellulose) contain different functional groups including alcohols, aldehydes, ketones, carboxylic, phenolic, and ether groups, which are able to bind heavy metals by electrons donation to form complexes in solution (Demirbas (2008); Pagnanelli et al. (2003)). The metal binding mechanisms thought to be involved in the biosorption process include ion exchange, surface adsorption, chemisorption, complexation, and adsorption–complexation (Demirbas (2008)).

In Al Rmalli et al. (2005) non-living, dried roots of the water hyacinth plant (*Eichhornia crassipes* (Mart.) Solms) could rapidly remove arsenic from water. More than 93% of arsenite and 95% of arsenate were removed from a solution containing 200 µg/L As within 60 minutes of exposure to powdered dried roots. The amount of arsenic remaining in solution was found to be less than 10 µg/L. Such biomaterial, produced from a plant that is found in abundant supply in many parts of the world, can provide a simple, effective and yet cheap method for removing arsenic from contaminated water.

Khalid et al. (1998)investigated pretreated rice husk and obtained a maximum adsorption at 0.01 mol/L of HNO3, HCl, H_2SO_4 or $HClO_4$ using 1.0 g of adsorbent for 5.97×10^{-3} mol/L of arsenic for 5 min. The uptake of arsenic increased with increasing temperature. In another paper, Amin et al. (2006)utilized untreated rice husk. Complete removal (using rice husk columns) of both As(III) and As(V) was achieved under the following conditions: initial As concentration, 100 µg/L; rice husk amount, 6 g; average particle size, 780 and 510 µm; flowrate, 6.7 and 1.7 mL/min; and pH, 6.5 and 6.0, respectively. Desorption (71–96%) was also achieved with 1M of KOH.

Commercially produced empty fruit bunch biochar (EFBB) and a rice husk biochar (RHB) were also tested in Malaysia for As(III) and As(V) removal (Samsuri et al. (2013)). The effects of coating the biochars with Fe(III) on adsorption of As(III) and As(V) were also studied. The maximum adsorption capacity of both EFBB and RHB for As(III) was higher than for As(V), 18.9-19.3 mg/g and 5.5-7.1 mg/g respectively. Coating the EFBB and RHB with Fe(III) increased their capacity values for both As(III) and As(V) to 31.4-30.7mg/g and 15.2-16 mg/g respectively.

Limited research has been conducted on the biosorptive removal of arsenic via other agricultural waste materials including coconut coir pith, orange waste (Ghimire et al. (2003)), olive pomace, sawdust, and tea waste (Demirbas (2008); Pagnanelli et al. (2003)).

4.4 Membrane-based technologies

Technology information sheet	TR-07

Highlights – Arsenic and salts are removed by filtration through membranes. Depending on membrane pore-size, other contaminants (e.g. pathogens, organic matter, pharmaceuticals, salinity) can be removed as well. Expensive membranes, high energy demand and costs related to monitoring experts (because of fouling) make this method unsuitable for arsenic removal alone.

Membranes can remove arsenic and salts through filtration, electric repulsion, and adsorption. On the other hand, membrane methods can thus be used to tap alternative water resources (i.e. purify brackish water or seawater) for the production of drinking water. The viability of microfiltration and ultrafiltration as a technique for arsenic removal is highly dependent on the size distribution of arsenic-bearing particles in the source water. However, arsenic found in groundwater is typically less than 10 percent particulate (Pirnie (2000)), making such low-pressure membrane processes less suitable for As removal, when pre-oxidation and coagulation is not applied. Nano-filtration and Reverse Osmosis membranes are capable of removing significant portions of the dissolved arsenic compounds in natural waters by size exclusion. Several bench and pilot-scale studies reported arsenic rejections percentages varying largely (3% to >95%) dependingn operating parameters, membrane properties, water matrix composition (i.e. suspended solids, organic matter, hardness, sulfides, ammonium, pH), and arsenic speciation. Efficiency in removing As(V) was higher than for As(III) and oxidation is not an easy way to improve the efficiency since some oxidants could damage the membrane (Shih (2005)). Comprehensive revisions, covering other complementary aspects, can be found in Brandhuber and Amy (1998) and Shih (2005). Well defined performances and no need for additional chemicals make this technology prompt to automation, lowering operation and maintenance requirements. Anyway, trained personnel needs to continuously monitor the operation and efficiency of the system, and to chemically clean the membranes to keep water production at a desired level. The main disadvantages are low water recovery rates (10-20% in case of single membrane module), high electrical consumption, high investment costs, concentrated brine production, and risk of (bio)fouling.

4.4.1 NF and Low-Pressure RO

Technology information sheet	TR-07

Highlights – Efficient removal methods but at a relatively high cost and an additional requirement is the maintenance of a membrane-based method. They are potentially applicable in the Bangladeshi context, but current developments in membrane manufacturing will largely determine future affordability and applicability of these methods.

In developing countries, low annual income and low electric popularization make it complicated to apply traditional high-pressure membrane technology due to its high energy consumption. Therefore, a low pressure NF based arsenic removal technology without electric energy requirements was designed by Oh *et al.* (2000).Using a NF membrane coupled with a bicycle pump operated at 4 MPa, the arsenate rejection efficiency reached over 95%, while arsenite rejection was limited to 55%. Chang et al. (2014) evaluated the As(III) rejection and water production of a NF membrane and a low-pressure RO membrane in different conditions. In addition to the smaller membrane pore size, the low-pressure RO membrane possesses much more dissociable functional groups than the NF membrane, leading to a As(III) rejection of 65% compared to 10% reached by NF when the feed pH was below the pKa_1 value (9.22) of H_3AsO_3, for which size exclusion was the only rejection mechanism.

Sen et al. (2010) evaluated the removal of As by preoxidation of As(III) to As(V) using $KMnO_4$ followed by NF. They found that the overall As removal increased from 50–63% to 97–100% and total As was removed below 10µg/L from a starting concentration of 376 µg/L with an optimum oxidant dose of 5 mg/L. Coagulation-assisted membrane filtration (CAMF), particularly for low-pressure membranes, was considered by Chang et al. (2005) one of the most promising technologies for arsenic removal because it can be applied to a wide range of water qualities, including waters that contain high turbidity (surface water), iron, manganese, and other anions, such as sulfate and nitrate. CAMF, compared to conventional coagulation, required a smaller amounts of chemicals (as low as 1 mg/L of Fe(III) for the formation of smaller flocs) and generated a lower quantity of waste.

However, several issues still remain to be resolved before any chemical pretreatment can be applied optimally in the water treatment membrane field. These issues include the impact of chemical pretreatment on membrane reversible fouling and chemical cleaning frequency, the compatibility of these chemicals with membrane materials, the optimum conditions for chemical pretreatment, and overall cost and benefits of chemical pretreatment to MF and UF membrane systems (Farahbakhsh et al. (2004)).

4.4.2 Energy Recovery Systems and Renewable Energy Powered Reverse Osmosis

The use of alternative and locally available sources of energy combined with systems for energy recovery can significantly increase the range of water resources a community can use.

A small photovoltaic/RO plant with a capacity of around 1 m^3/d was installed on the island of Gran Canaria (Herold and Neskakis (2001)). Wind-powered desalination is another option that seems to be attractive. Again on the Canary Islands, two wind powered RO systems are operated on different islands of the archipelago (García-Rodríguez et al. (2001)). Wind power can significantly reduce the unit cost of produced water in RO, provided that the wind mean velocities on location are higher than 5 m/s (Kiranoudis et al. (1997)).

Watermakers or other small-scale marine RO units used to produce drinking water from seawater on boats can also possibly be used for As removal. Some of these units can be powered by sustainable energy sources such as photovoltaic, wind wheels, or can be operated manually. Small-scale RO units were tested for their performances in terms of As removal (Geucke et al. (2009)). The experiments were conducted with arsenic-spiked tap water, using As(III) and As(V) up to feed concentrations of 2400 µg/L. As expected, the As(V) rejection was generally much better than the one of As(III). With two of the tested membranes As(V) rejection reached values >99%, with the permeate water quality complying with the WHO recommended maximum contaminant level of 10 µg/L even at a feed concentration of 2400 mg/L. In the case of As(III) only feed concentrations below 350 µg/L resulted in permeate concentrations below 10 µg/L. The use of an energy recovery system is able to lower the energy consumption by 80%, taking advantage of stored energy in the high-pressure reject water that is typically wasted in conventional systems and therefore lowering the price of drinking water production to an estimated 0.01 €.

Another innovative technological solution to lower energy requirements in membrane systems for large water production is the PURO-concept (Timmer et al. (2011)). The RO system is installed in a groundwater well at a depth of 170 m to exploit the water pressure naturally present. The RO-unit treats the water underground and discharges the concentrate in a deeper confined aquifer presenting salinity level similar to the brine. The treated water extraction and the transportation of the concentrate to a greater depth are expected to lead to an overall energy gain of roughly 40% when compared with conventional surface treatment. The environmental impact is still to be assessed.

4.4.3 New Developments: Forward Osmosis, Membrane Distillation, Capacitive Deionization, and Electrodialysis Reversal

- **FORWARD OSMOSIS**

Highlights – Arsenic is removed by filtration through a membrane, powered by a salt gradient. Removes multiple contaminations such as arsenic, pathogens, natural organic matter and dissolved salts. The permeated water needs to be separated from the draw solution in a secondary treatment which is energy demanding and costly. Membrane costs and technical sophistication reduce current applicability in Bangladesh.

Forward osmosis (FO) (Figure 13) is another membrane process that in recent years has been adopted for treatment of industrial waste streams, landfill leachate, activated sludge, and seawater desalination (Cornelissen et al. (2008); Cath et al. (2006)). The natural process at the base of FO requires two solutions: a feed solution and an osmotic (draw) solution, together with a dense, non-porous and selectively permeable membrane. The draw solution presents an osmotic concentration higher than that of the feed, in order to induce a net water flow through the semi-permeable membrane towards the draw side. Water from the As-contaminated feed solution is transferred through the membrane to a proper draw solution, while As is rejected and remains in the concentrated feed solution. The diluted draw solution needs to be then separated from the produced water in order to be reused in the process.

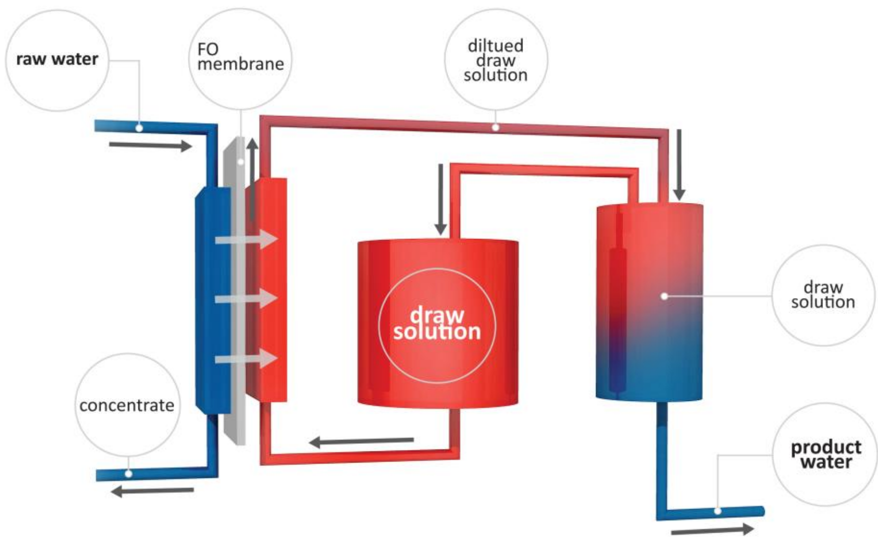

Figure 13 Forward osmosis system schematic

There is a lower probability of membrane fouling compared to other membrane processes. Together with the low energy consumption and the simplicity of the process, this makes the FO a very promising, low cost and energy efficient process (Lutchmiah et al. (2011)). At the same itme, it should be noted that the draw solution requires special attention that necessitates some financing and energy. Jin et al. (2012) investigated the removal of As using FO combined with the influence of membrane orientation and the occurrence of membrane fouling. The rejection was better when the surface active membrane side faced the feed water compared to draw water. Various NaCl solutions were used as draw solutions. Arsenic was removed from solution with a removal efficiency increased from 70% to >90% when the water flux was increased from 2.5 to 7µm/s. Alginate fouling had a minor effect on water flux, while enhancing As-removal as a result of improved sieving effect.

- **MEMBRANE DISTILLATION**

Highlights –Broad purification range and desalination properties, based on a temperature difference. No chemicals needed. With sustainable power source promising for remote areas with high salinity. Low output, expensive membrane and costs related to monitoring experts (because of fouling) reduce applicability.

Membrane distillation (MD) has been particularly used for desalination of seawater (Van der Bruggen and Vandecasteele (2002)). MD is a thermally driven process and involves transport of water vapor through a porous hydrophobic membrane. After evaporation of the volatile molecules from the hot feed, due to vapor pressure differences across the membrane, transport of volatile molecules takes place. Among the different kinds of MD, direct contact MD (DCMD) is the most simple, economical and efficient technique where the hot feed and the cold permeate are directly separated by the membrane. In the last decade DCMD was investigated for the removal of As (Manna et al. (2010); Pal and Manna (2010); Pal et al. (2013); Qu et al. (2009); Yarlagadda et al. (2011)). Pal and Manna (2010) demonstrated that nearly 100% of the As was removed from the contaminated groundwater with a reasonable high flux of 49.80 kg/(m^2 h) with a solar driven MD. In another study, Qu et al. (2009) could obtain As(III) and As(V) concentration in the permeate below 10 µg/L for As(III) and As(V) concentration in the feed of 40 and 2500 mg/L, respectively. Moreover, DCMD has several advantages over other conventional and pressure driven membrane processes: (i) no need for chemicals treatment,(ii) local waste heat and renewable energy source may be used, (iii) no need for high pressure, (iv) the process is independent from the composition and the pH of the feed,(v) both As(III)and As(V)removal efficiencies are high, and (iv) it saves costs for the treatment of contaminated waste or sludge (Mondal et al. (2013)).

Criscuoli et al. (2013) analyzed the potential of vacuum membrane distillation (VMD) at low feed temperatures (20°C-40°C) for treating water containing both As(III) and As(V). The membrane area was 180 cm^2 and the vacuum pressure was fixed at 10 mbar. Arsenic was not detected in the permeate at all configurations tested. Long-term tests confirmed the efficiency of the process. The highest flux ranged between 3 and 12.5kg/hm^2 at 20°C and 40°C.

- **CAPACITIVE DEIONIZATION (CDI)**

Highlights – A simultaneous removal of several charged species (e.g, As(V), salinity) without the use of chemicals. A pre-oxidation step and subsequent disinfection is necessary for the production of safe water. Requires trained personnel. Unsuitable for arsenic removal alone. Restricted applicability in areas with brackish water sources, if coupled to a sustainable energy source.

CDI has emerged over the years as a robust, energy efficient, and cost effective technology for desalination of brackish water (Zhao et al. (2013a); Porada et al. (2013)). A capacitive deionization cell consists of two oppositely placed porous electrodes, and a spacer channel in between for water to flow through. When charging the electrodes with an external direct current energy source, the ions in the water stream are adsorbed into the micropores of the electrodes (adsorption step) and desalinated water flows out of the cell (see Figure 14). This process is based on the formation of electrical double layers inside the intraparticle pores. If either the cell is short-circuited or the current is reversed, the adsorbed ions are released back into the flow channel (desorption step) and flushed out with a small quantity of liquid. In this way, a small stream enriched in ions is produced and the electrodes regain their initial ion uptake capacity. The system can also present ion exchange membranes in front of each electrode, namely a cation exchange membrane in front of the cathode and an anion exchange membrane in front of the anode, to obtain a membrane CDI, or MCDI. MCDI has been proven more efficient in terms of ions adsorbed per gram of total electrode mass, thus the membranes ensure a lower energy consumption (Zhao et al. (2013b)).

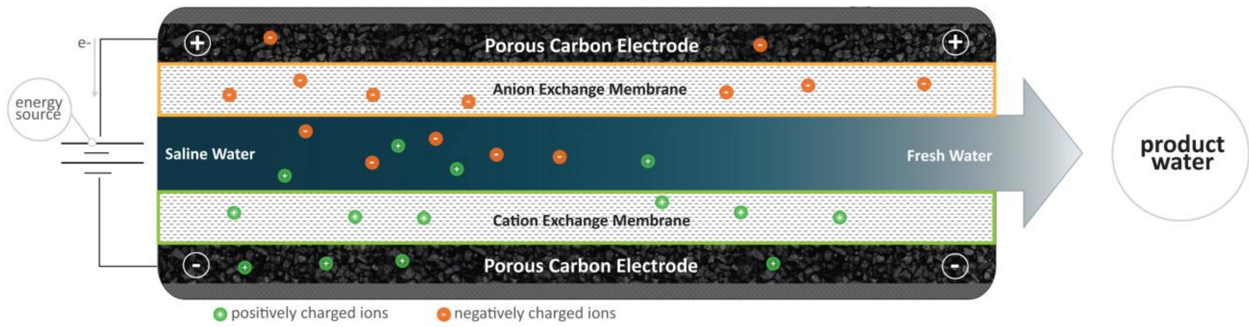

Figure 14 Schematic view of a MCDI

Zhao et al. (2013a) indicated that MCDI is more convenient in terms of energy consumption compared to RO when the influent TDS concentration is below ~2.5 g. Other advantages include a low voltage and minimal electrical safety requirements, and the potential for coupling with the local solar energy supply in remote areas (Anderson et al. (2010)). Ideally, this process is purely physical and enables CDI devices to have a long service life and low maintenance. Garrido et al. (2008) applied this technology to desalinate As-rich potable water source in Huautla, Mexico. The concentration of As in the treated water remained below detection limits (<5 µg/L) despite a raw water concentration as high as 820 µg/L. Mossad and Zou (2013) and Zhang et al. (2013) indicated that total organic carbon presence in the CDI feed solution lowered the salt removal efficiency and production rate, increasing the energy consumption. Dissolved organic matter is problematic in terms of electrode fouling, as it blocks the activated carbon pores and reduces their electrosorption capacitance. Ca and Mg had no noticeable effect on the performance, while Fe seemed to have a great impact on long-term CDI treatment efficiency. Chemical (alkaline and acid) cleaning solutions were able to restore the recovery of the performance. Pre-treatment to reduce the dissolved organic matter levels was recommended to achieve sustainable treatment performance.

- **ELECTRODIALYSIS REVERSAL**

Highlights – Arsenic is removed together with other charged species (e.g, As(V), salinity) without the use of additional chemicals. Expensive treatment, as it requires a power source and readjustment of the water quality after treatment. At present, limited relevance for Bangladesh.

With the term electrodialysis (ED) Strathmann (1994) defined an electrochemical separation process in which ions are transferred through ion-exchange membranes by means of a direct current. An ED module consists of two dilute (product) chambers and one concentrate (waste) chamber, separated by cation and anion semi-permeable membranes (see Figure 15). An electrical potential difference across an alternating series of ED modules between an anode and a cathode initiates the migration of the ions in solution toward their respective electrodes. Anions can pass through the anion-exchange membrane, but not through the cation-exchange ones. On the contrary, cations can pass through the cation-exchange membrane, but they are retained from the anion-exchange one. The overall result is that an electrolyte (i.e. a salt or an acid or a base) is concentrated in alternate compartments while the other solutions are depleted of ionic components (Strathmann (2010)).

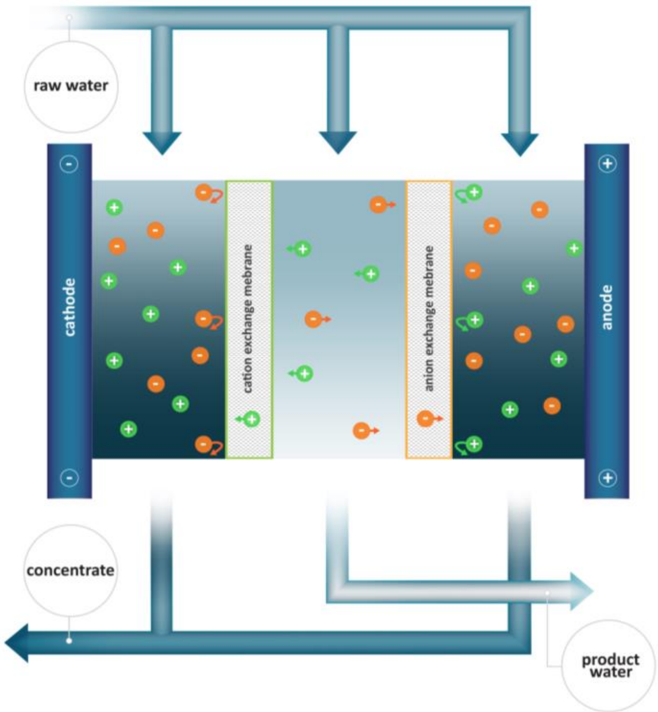

Figure 15 Schematic representation of electrodialysis

ED reversal (EDR) has been implemented to minimize fouling. By reversing in certain time intervals the polarity of the applied electrical potential, charged particles that have been precipitated on the membranes can be removed. Major advantages are the continuous regeneration without extra chemicals and the relatively high current efficiency.

Ribeiro et al. (2000) used ED for the batch removal of arsenic from waste of wood treated with chromated copper arsenate. The authors extracted 26.7, 98.7, 96.6 and 92.2% arsenic from sawdust by using distilled water, 2.5% oxalic acid, 5.0% oxalic acid and 7.5% (w/w) oxalic acid, respectively. In all the experiments, the current density was 0.2 mA/cm^2, and duration of treatment was 30 days.

Jensen et al. (2012) demonstrated the feasibility of electrodialysis reversal (EDR) for treatment of suspended sludge derived from As-rich soil washing. As was removed with an efficiency in the range 36%-75% depending on the water matrix, with starting concentrations as high as 9260 mg/L.

4.5 Biological Processes

Technology information sheet	TR-08 TR-09

Biological removal processes by indigenous bacteria can play an important role in catalyzing many of the chemical processes involved in As removal. Depending on the physical-chemical condition of the environment, some arsenic compounds can be highly soluble, resulting in a high level of bioavailability. Its toxicity and bioavailability depend on its speciation, which in turn, can be influenced by microbial transformations. Biological and microbiological methods can represent economically viable as well as environment-friendly alternatives for arsenic removal. Active treatments of arsenic-contaminated waters benefit from the knowledge of arsenic bacterial metabolism. However, many studies were confined to laboratory and need to be tested under real-scale conditions to assess their viability. The biogeochemical cycle involves several physical-chemical processes (i.e., oxido-reduction, precipitation/solubilisation, and adsorption/desorption processes) as well as biological mechanisms, especially those involving bacteria, such as As(V) reduction, As(III) oxidation and the various methylation reactions. These reactions protect bacteria from the toxic effects of arsenic by enhancing their resistance mechanisms, and in the case of some species, contribute to energy metabolism processes (Lièvremont et al. (2009)).

A wide range of bacteria isolated from various contaminated environments were described for their ability to synthesize arsenate and thus to oxidize As(III) enzymatically. They include heterotrophic bacteria as well as chemoautotrophic bacteria in which As(III) serve as an electron donor reducing oxygen or nitrate. In this latter case, the energy produced is used to fix CO_2, which provides bacteria with the carbon required for growth. In populations where both heterotrophic and chemoautotrophic bacteria are present, heterotrophic As(III)-oxidizing bacteria can develop using organic substances synthesized by chemoautotrophic bacteria (Battaglia-Brunet et al. (2002)). The biological oxidation of As(III) to As(V) by iron and manganese oxidizing bacteria has been reported and it was also confirmed that trivalent arsenic can be efficiently treated without any additional use of chemicals in this bioprocess (Casiot et al. (2003)). The bioconversion of arsenite can also be accomplished via methylation or oxidation-reduction of the arsenic species found in the water. Their bioconversion efficiency can be increased by genetic modification of the intervening microorganisms (Kostal et al. (2004)). The study of microbial biofilms metal dynamics in acid rock drainage provided evidence of the stable accumulation of metals in these bioreactors, in which secrete polymers are able to immobilize metal compounds by passive sequestration processes, avoiding its use to develop bioremediation methods. In the presence of arsenic, bacteria such as *H. arsenicoxydans* produce large amounts of exopolymers that can be used to detoxify natural waters contaminated with arsenic (Muller et al. (2007)).

Bacterial sulphate reduction is recognised as a mechanism for sequestering metals in contaminated environments, primarily through precipitation of metal sulphides. The sulphide produced by bacteria can reduce As(V) and precipitate As(III) in sulphide phases (Kaksonen and Puhakka (2007)) .
New developments in the biotechnological field have focused on phyto-remediation and biofiltration processes (Katsoyiannis and Zouboulis (2004)) that have revealed to be efficient and environmentally sustainable. In phyto-remediation, plant and fungal biomass is used as a renewable adsorbing material in a process that is similar to chemical compound removal. The adsorbing capacity of this biomass is superior to that of activated carbon and of some synthetic resins used in water treatment.

4.5.1 Microbial-assisted arsenic removal technologies

Technology information sheet	TR-08

Highlights – Arsenic is biochemically oxidized by microorganisms, and removed in a subsequent filtration step. If optimized, the system can remove other undesired contaminants (e.g., nitrate, pathogens, iron). Monitoring of operation (e.g., clogging) and removal efficiency is essential. Positive field-scale operations in India.

Several microbial-assisted arsenic removal technologies have been attempted both in laboratory and field scale. Wan et al. (2010) developed an up-flow fixed-bed bioreactor combined with biological As(III) oxidation and adsorptive removal of arsenic by zero-valent iron. For the biological oxidation of As(III) previously isolated As(III)-oxidizing bacteria were immobilized on silica sand. In a pilot study lasting 33 days, the maximal As(III) oxidation rate was 8.36 mg/(L h) with about 45%of total arsenic removed in the second column and having a hydraulic residence time of 1 h. Katsoyiannis et al. (2004) investigated the removal of arsenic from groundwater in a bioreactor by iron-oxidizing bacteria *Gallionella ferruginea* and *Leptothrix ochracea*. Such bacteria oxidized Fe(II) present in the groundwater which subsequently precipitated as iron oxides in the filter medium (polystyrene beads). As iron oxides are efficient adsorbents of arsenic, the study showed that both As(III) and As(V) could be removed from contaminated groundwater with arsenic concentration 50–200 µg/L. As(III)-oxidation was also found to be catalyzed by those iron-oxidizing bacteria, leading to enhanced overall arsenic removal. Later, these authors (Zouboulis and Katsoyiannis (2005)) used the same system in a successful field test treating groundwater containing 60–80 µg As(III)/L over a 10 month period. A similar method was developed by Pokhrel and Viraraghavan (2009) with the iron oxidizing bacteria grown in the bioreactor by circulating groundwater for 15 days through a sand filtration column. With a ratio 40:1 of iron and arsenic in tap water 100 µg/L arsenic could be removed below 5 µg/L in the bioreactor.

Upadhyaya et al. (2010) developed a bioreactor system, consisting of two biologically active carbon (BAC) reactors in series, for the simultaneous removal of nitrate and arsenic from a synthetic groundwater supplemented with acetic acid. A mixed biofilm microbial community that developed on the BAC was capable of utilizing dissolved oxygen, nitrate, arsenate, and sulfate as the electron acceptors. Nitrate was removed from a concentration of approximately 50 mg/L in the influent to below the detection limit of 0.2 mg/L. Biologically generated sulfides resulted in the precipitation of the iron sulfides, which simultaneously brought arsenic concentration from 200 µg/L to below 20 µg/L through arsenic sulfide precipitation and surface precipitation on iron sulfides.

Although a number of attempts have been made for the microbial-assisted removal of arsenic in laboratory experiments, only one technology has been set at field scale which has operated since 2006. Five integrated arsenic removal systems with 1,000 L/day filtration capacities have been designed and installed by Paknikar and his group in arsenic affected villages in India (Pal and Paknikar (2012)). This treatment plant is based on bio-oxidation - alumina/charcoal adsorption technology where oxidation of As(III) to As(V) is performed by As(III)-oxidizing bacteria *Mycobacterium lacticum* followed by sorption onto activated alumina/charcoal (Mokashi and Paknikar (2002); Pal and Paknikar (2012)). To support the growth of bacteria, additional carbon is added to the groundwater before entering the treatment plant. Even with some limitations, this technology seems to be a promising one for arsenic affected low-income communities.

4.5.2 Phytofiltration

Technology information sheet	TR-09

Highlights – Arsenic is removed by the metabolism of living plants. Large area required to grow the arsenic-hyperaccumulating ferns. A periodical monitoring of the produced water and of the well-being of the plants by trained personnel is essential. Post treatments include disinfection and sand filtration. Use in flood-prone areas is questionable.

The potential of using recently identified arsenic-hyperaccumulating ferns to remove arsenic from drinking water was investigated by Huang et al. (2004). Hydroponically cultivated, two arsenic-hyperaccumulating fern species (*Pteris vittata* and *Pteris cretica* cv. Mayii) and a non-accumulating fern species (*Nephrolepis exaltata*) were suspended in water with initial arsenic concentrations ranging from 20 to 500 µg/L. The efficiency of arsenic phytofiltration by these fern species was determined by monitoring the depletion of 73As-labeled arsenic concentration in the water. At similar plant ages, both *P. vittata* and *P. cretica* had similar arsenic phytofiltration efficiency and were able to rapidly remove arsenic from water to achieve arsenic levels below the new drinking water limit of 10 µg/L (>98% removal in 24h). However, *N. exaltata* failed to reduce arsenic concentrations to achieve the limit under the same experimental conditions. The significantly higher efficiency of arsenic phytofiltration by arsenic-hyperaccumulating fern species is associated with their ability to rapidly translocate absorbed arsenic from the roots into its fronds (Ma et al. (2001)). Arsenic-phytofiltration technique based on these ferns may provide the basis for a solar-powered hydroponic technique that enables small-scale treatment of arsenic-contaminated drinking water.

Also aquatic and wetland plants, commonly found in contaminated areas, can remove arsenic. Among plants commonly used in this method are alum, phragmites, vetiver grass, and cattail. Among these plants, alum (*Colocasia esculenta*) was best at removing arsenic (Visoottiviseth and Ahmed (2008)). As plants grow and absorb arsenic, they are harvested, and new plants are seeded to repeat the process. Wetland treatment in Thailand removed more than 90% of arsenic from surface water.

4.6 In-Situ Remediation

Technology information sheet	TR-10 TR-11

In-situ based technologies have lower operation costs in comparison with on-site or off-site treatment as the classical "pump and treat" technologies. Different approaches have been applied, among others permeable reactive barriers, chemical oxidation, multiphase extraction, and supervised natural attenuation, and Subsurface Arsenic Removal.

4.6.1 Permeable Reactive Barriers

Technology information sheet	TR-10

Highlights – Arsenic is removed directly in the subsoil without the addition of chemicals. Other contaminants are also removed by this treatment, even though performances require monitoring. Expensive treatment, no practical applications were documented for Bangladesh so far.

The use of permeable reactive barriers (PRB) and reactive zones is considered as one of the most efficient technologies for in-situ removal of As. In PRB technology, a reactive medium is interposed in the way of the contaminant plume as shown in Figure 16. The appropriate reactive material is able to induce physicochemical and/or biological processes to remediate groundwater contamination. Fe (or Al) oxide-containing materials can be used as relatively cheap passive reactive barriers (Bhattacharya et al. (2002);Gavaskar (1999) ; Gu et al. (1999)). The involved main processes are sorption, precipitation, chemical reaction and/or biogenic reactions (Di Molfetta and Sethi (2012)). Lackovic et al. (2000) proposed a mixture of iron oxides with silica and calcite for As removal, to enhance adsorption and/or coprecipitation of the anionic species. Long-term microbiological and geochemical processes have a great impact on the durability of the barrier, together with the degradation of the material by corrosion. Even if major failures of PRB's have not been problematic, the accumulation of iron oxyhydroxides, carbonates, and sulfides from biogeochemical processes could reduce the reactivity and permeability of the reactive barrier, thereby decreasing treatment efficiency (Gu et al. (1999)). The technology has been directed recently to the use of zerovalent iron, as a new sorption medium to remove both arsenate and arsenite. Gibert et al. and Su and Puls achieved values below 10 µg/L in their studies (Gibert et al. (2003);Su and Puls (2003); Su and Puls (2001)). Further research should be dedicated to the application of micro- and nanoparticulate ZVI (M-NZVI) as reactive barrier for As (Kanel et al. (2007)). M-NZVI small dimensions are suitable for injection directly in the aquifer system, overcoming the depth limits due to excavation of PRB's (Tiraferri et al. (2008); Wang and Zhang (1997)).

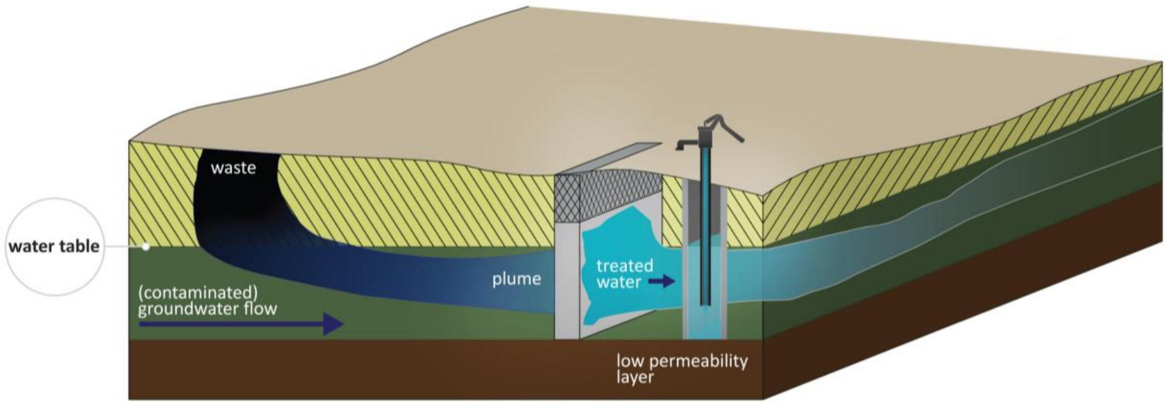

Figure 16 Conceptual scheme of PRBs (Litter et al, 2010)

4.6.2 Subsurface Arsenic Removal

Technology information sheet	TR-11

Highlights – Arsenic is removed directly in the subsoil. Other contaminants (e.g., Fe, trace contaminants, phosphate) are also removed during the treatment. Operation is simple and does not require specialized personnel. Rate of safe water production is low. Technology efficiency has been found vulnerable to the diversity of geochemical conditions common in rural Bangladesh.

Subsurface iron removal for the retention of high arsenic concentrations from groundwater is a new approach with great potential for both iron and arsenic removal (Van Halem et al. (2010a)). The principle of subsurface arsenic removal is that aerated water is periodically injected into an anoxic aquifer through a tube well partially displacing the iron-containing groundwater. Figure 17 illustrates the principle of SAR. The injected oxygen-rich water oxidizes adsorbed ferrous iron on the soil grains, resulting in a surface area of ferric iron hydroxides suitable for adsorption and co-precipitation of soluble ferrous iron and trace elements such as arsenic. When the flow is reversed, soluble ferrous iron in the abstracted groundwater is adsorbed onto the ferric iron coated soil grains and water with reduced iron and arsenic concentrations is abstracted. Injection is started again once elevated iron levels arrive at the well. The affected area in the subsurface around the tube well is referred to as the oxidation zone. However, this technology proved to be highly site specific for arsenic removal (Moed et al. (2012); van Halem et al. (2010b)), while it demonstrated great potential for iron removal as decentralized application at community scale. Under low phosphate conditions, subsurface arsenic removal has shown improvement after successive cycles compared to other field studies. However, the ratio of production of safe drinking water is still low. Subsurface Arsenic Removal has been found to be less effective and vulnerable to the diversity of geochemical conditions common to rural Bangladesh.

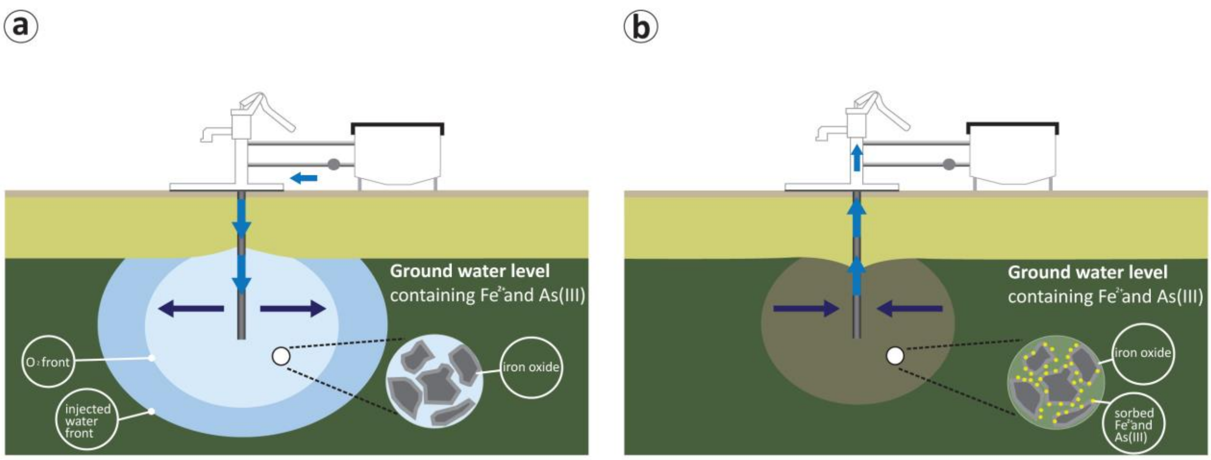

Figure 17 Scheme of principle of subsurface iron and arsenic removal

4.7 Specific desalination treatment of brackish groundwater

Technology information sheet	TR-07 TR-12

Highlights – A treatment group that focuses on brackish water alone and increases in importance with the growing salinity stress in the Southern regions of Bangladesh.

The coastal region of Bangladesh has seen a major increase in salinity of its natural water and soils. In the last two decades sea level rise, climate change, and anthropogenic alteration of natural settings brought severe consequences to both potable and agriculture water due to moderate-high levels of salinity. Besides, the changes of natural water flow by the neighboring India has already created a huge water scarcity in the southern-eastern part of Bangladesh (Miah et al. (2010)). The upstream reduction of natural water flow is also contributing for increasing level of salinity problem in coastal areas of Bangladesh (SRDI (2009)). While describing key priority activities, the National Adaptation Program of Action (NAPA) initiated a series of projects that would assist the government to combat against climate change and its consequence hazards. Out of 15 projects one of them particularly focused on drinkable water supply to coastal communities who are vulnerable due to high water salinity (NAPA (2005)).

In 2011, the Bangladesh Agricultural Development Corporation (BADC (2011)) identified the state of underground salinity front for the first time in the country using latest technologies. From the updated zoning map, it is revealed that in many areas of the country, groundwater levels have gone down below the mean sea level ranging from 0 to 52 meters. Some of these areas are connected among themselves and to the Bay of Bengal causing favorable conditions for saline water intrusion. The highest depletion took place in the capital city Dhaka. Before 2004, the underground vacuum of Dhaka city was recharged by the water flowing from northern aquifers, but at present these areas are suffering from severe depletion of groundwater level. Thus, the only way to be recharged is now by the water flowing from the South saline sea, and the salinity front is moving North at a depth of approximately 34 m.

Desalination represents a potential technology group for the efficient production of water in presence of salinity intrusion. Desalination may be applied to waters of varying levels of salinity, such as brackish groundwater, estuarine water or seawater. Reverse osmosis filtration and multi stage flash evaporation are the most applied technologies (GWI-IDA (2013)), but their installation largely depends on energy availability. Other desalination technologies rely on evaporation (i.e., solar distillation), crystallization, evaporation and filtration (membrane distillation), ionic migration (electrodialysis), and more.

Costs associated with desalination depend on many site specific factors (feed water characteristics, product water quality, plant capacity) with energy availability being the most critical. Removal of lower concentrations of dissolved salts results in lower treatment costs (Georgopoulou et al. (2001)), which makes brackish water desalination more economically feasible compared to sea water. Even though desalination costs over the last decades steadily decreased (Reddy and Ghaffour (2007)), desalination is still an expensive option compared to natural water resources and further research is needed to consolidate it as a competitive alternative. The use of renewable energy instead of fossil fuel would reduce both cost and hazards of desalination, enhancing the sustainability of desalination processes (García-Rodríguez (2002)). In chapter 4, some of the technologies adopted for brackish water desalination will be thoroughly discussed, yet associated with the removal of arsenic.

4.8 Waste and Sludge Management

All arsenic removal systems, except in-situ remediation, generate solid or liquid waste. A first distinction has to be made between spent sorbents and sludges on the one hand, and concentrated liquid wastes on the other. Liquid wastes proceeding from membrane filtration or from the regeneration of IX and other sorbents are challenging and require a mature waste-management industry and regulatory framework for proper disposal (Sorg (2000); Ravenscroft et al. (2009)). On the other hand, spent sorbents and sludge are often assessed for their stability and leachability using tests which quantify the extent of extraction of arsenic from a solid waste using a single solution as leachant. For a comprehensive review of arsenic waste testing procedures see Clancy et al. (2013). Many of these tests, including the already mentioned TCLP (EPA (1992)), focus on differentiating hazardous waste, which requires disposal in a hazardous waste landfill, from nonhazardous waste, suitable for discarding in municipal solid waste landfills. The characterisation depends on the resulting concentration of contaminant in the leachate. In developing countries, wastes classified as suitable for nonhazardous landfill disposal are often claimed to pose no concern for disposal conditions that differ greatly from landfills and, in the absence of any clear guideline for safe disposal, such wastes are often disposed in the open environment (Ali et al. (2003); Leupin et al. (2005)). Some researchers even stated that small amounts of sludge or solid waste contaminated with arsenic could be disposed into moving water bodies (Leupin et al. (2005)) or directly on soil (Hussam et al. (2008)). Nevertheless, the stability and disposal of As-rich sludge and spent sorbents evoke concerns (Badruzzaman (2003)), and recent research showed that the TCLP may significantly underestimate arsenic mobilisation (Clancy et al. (2013); Ravenscroft et al. (2009); Leist et al. (2003)).

Clancy et al. (2013) reported that a common method for the disposal of sorptive filter media and regenerative wastes in developing countries is dumping of the wastes into small sand covered brick-lined pits. Raw sludge is often air dried before disposal to decrease the bulk of waste to be managed. Pits are typically about 1 m^3, are rarely sealed, and are apt to flooding, leading to potential leaching into the surrounding soil and eventually to the groundwater. Several studies (Ali et al. (2003); Eriksen-Hamel and Zinia (2003); Ahmed (2003); Shafiquzzaman et al. (2010)) used the TCLP to analyse waste media from a number of different types of traditional removal filters and HWTS's in order to determine if landfill sludge disposal methods were safe and As could not return to contaminate the environment. They detected negligible concentrations of As in the extraction fluid and concluded that none of the samples could be classified as hazardous. However, since TCLP analysis is designed to simulate leaching that takes place in a US EPA-recommended sanitary landfill and not open dumping in a country such as Bangladesh, modification of the TCLP to represent a natural leaching environment should be implemented (Badruzzaman (2003)).

Sarkar et al. (2010) designed a coarse sand filter chamber for the storage of As-rich solid waste. The inside of the chamber is kept aerated using passive vent pipes so as to avoid the development of anoxic conditions (see Fig. 18). Oxic conditions ensure that arsenate will remain bound to the resins / iron hydroxides / aluminum hydroxide media. This disposal option has been implemented in West Bengal, India, where over 200 community based arsenic removal filters have been installed. Field testing of leachate collected at the bottom of the coarse sand filter confirmed that it does not contain any significant concentration of arsenic.

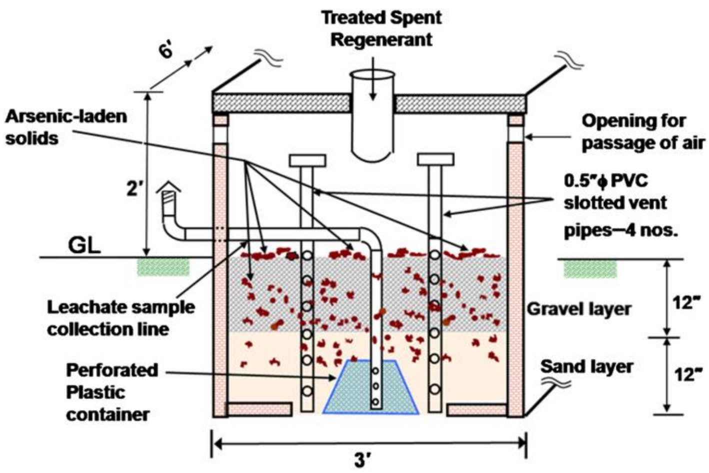

Figure 18 Schematic of an aerated coarse sand filter for containment of As-rich solid waste (Sarkar, 2010).

Decreasing solid phase arsenic concentrations were observed after mixing arsenic wastes with cow dung (Das et al. (2001)). This approach is intended to promote microbial arsenic methylation to produce gaseous methylarsines that are less toxic to mammals than inorganic forms. Although limited additional research has been performed to indicate that substantial arsenic removal could be achieved through volatilization, mixing arsenic-bearing wastes with cow dung has since been recommended as an optimal disposal strategy, especially for rural areas in developing countries (Visoottiviseth and Ahmed (2008); Mudgal (2001); Ali et al. (2003)) . Insufficient research is available assessing the potential for arsenic release in the aqueous phase following the contact of the As-rich waste and the livestock waste (Clancy et al. (2013)), particularly important when open dumping is considered as an option.

Stabilization and solidification of hazardous waste to reduce the toxicity and mobility of contaminants is a common treatment strategy (Raj et al. (2005); Conner (1990)). This is often accomplished through the addition of lime, concrete, or iron containing amendments, in order to reduce waste/leachant contact and to form a stable pH environment in which arsenic and other heavy metals remain insoluble. Following stabilization, arsenic wastes have been disposed on soils (Kumpiene et al. (2008)), in landfills (Sri Bala Kameswari et al. (2001)), or used as construction materials. Incorporation of As sludge into construction materials is common in urban areas of Bangladesh and India (Sullivan et al. (2010)). Typical products include cement blocks and cement plinths for latrines, and bricks or cement to produce construction blocks for housing. Experiments have also been used to develop ways to reduce leaching from arsenic wastes stabilized with amendments. In Rouf and Hossain (2003), higher firing temperatures correlated with slight decreases in leaching from bricks using different extraction liquids, including distilled water and rainwater. Environmental conditions including pH, relative humidity, and wetting and drying cycles impact the leaching of arsenic from stabilized wastes (Sanchez et al. (2002)). In addition significant health issues are also related to the amount of As containing dust generated during manufacture and construction (Rouf and Hossain (2003)).

In rural areas of developing countries, including Bangladesh, ponds are sometimes used as the ultimate disposal location for arsenic-bearing solid wastes from arsenic-removing sand filters and household filters (Shafiquzzaman et al. (2009)). During filter maintenance, slurries of water containing arsenic bearing iron hydroxides particles are disposed in ponds. Yokota et al. (2001) hypothesized that the arsenic from contaminated sludge could be adsorbed to sediment grains in the pond bed (co-precipitation with sediment grains in suspension) therefore keeping As-concentrations low. However, pond disposal is not widely studied, nor included as an option in many discussions of waste management.

Rahman et al. (2013) proposed chelant-washing (using 0.05 M EDTA) of the arsenic-loaded adsorbent combined with the solid phase extraction treatment to minimize environmental risks. The proposed process presented a cost-effective scheme, that included the option of chelant recycling next to the decontamination of the spent arsenic-rich sludge.

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5 Appropriate non-groundwater solutions

Technology information sheet	SD-05 Rainwater harvesting and storage SD-06 Managed aquifer recharge CO-01 Piped water supply schemes TR-12 Evaporation-based removal TR-13 Pond Sand Filter TR-14 UV disinfection TR-15 Chlorination TR-16 Boiling TR-17 Ceramic pot filter TR-18 Infiltration galleries TR-19 Riverbank filtration

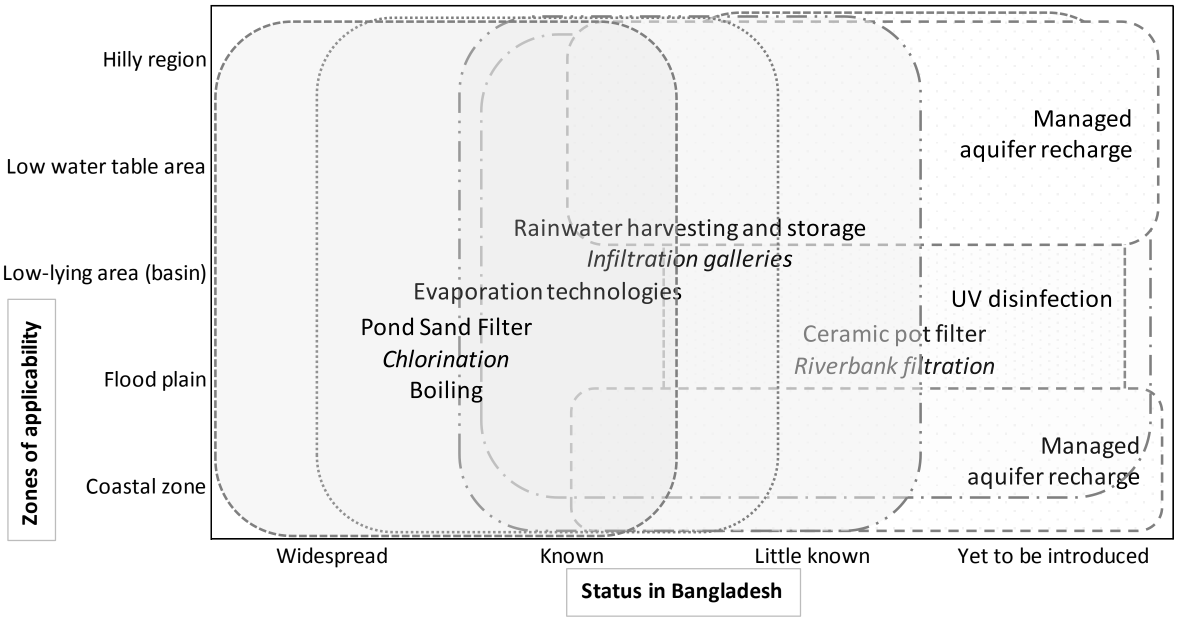

Figure 6 (Potential) use and experience of the identified alternative, non-groundwater water supply methods in Bangladesh

Water supply and treatment methods for the non-groundwater mitigation of arsenic and salinity are collected in this section (Figure 6). Possibly, this section is the most diverse approach as it contains well-embedded methods as Pond Sand Filtration but it also incorporates upcoming technologies as managed aquifer recharge or riverbank filtration. As the use of rainwater and in some cases fresh surface water can contribute to an increased sustainability of the Bangladeshi water sector, these methods deserve the focus of water experts and decision-makers.

5.1 Rainwater harvesting and storage

Technology information sheet	SD-05

Highlights – Especially relevant in the salinity-affected areas of Bangladesh. The precipitation profile of the country allows the efficient use of rainwater harvesting during 7-8 months per year. In the dry season, either proper alternatives or considerable storage facilities need to be provided. Combination with groundwater recharge has been shown to be effective in tackling salinity problem of shallow groundwaters.

Rainwater harvesting has been a common practice in Bangladesh since a long time (Chowdhury et al., 1987). A main distinction is made between roof water systems, which collect water for multiple use, and land surface catchments to manage water storage for agricultural purposes. The latter is not suitable for domestic use, as it concerns low quality water and infiltration losses are high. This chapter will focus on different types of roof water collection systems.

Rainwater harvesting serves as a major additional drinking water source in the saline coastal zones and arsenic affected areas in Bangladesh, where the consumption of groundwater is problematic (Shrestha, 2009). In areas with major freshwater shortages, such as the South-western Gourikhali, Kumkhali, Dacope, Ramnagar, Kaulashganj, and Shyamnagarin sub-districts, the water collected by roof systems is used during the whole year. Other areas are characterised by smaller storage systems, where rainwater is used as a complementary resource during the monsoon period, and eventually up to the first four dry months (UNEP, 2014a).

This chapter will first elaborate the principle of roof water collection systems for both private and communal uses. It will then proceed to discuss the principle and case of well recharge as a specific storage method for rainwater harvesting, and show the results from an applied case in India.

5.1.1.1 Roof water collection

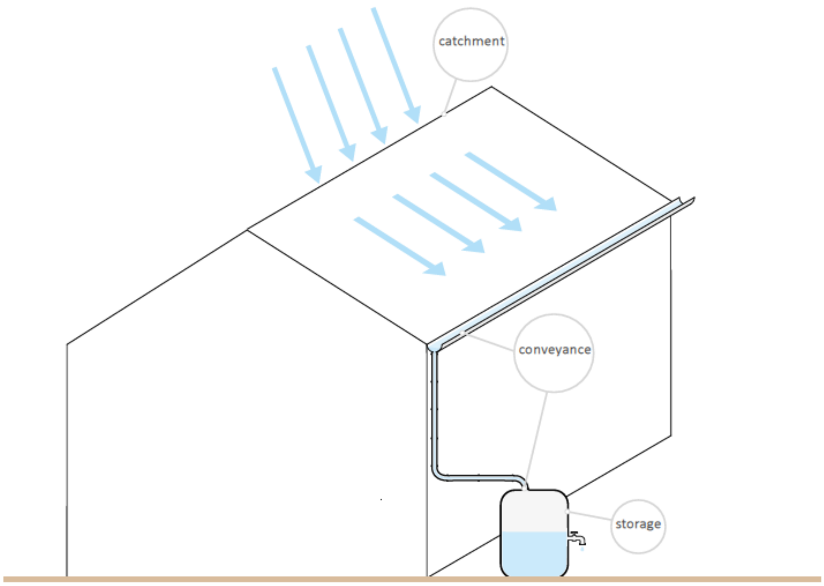

Figure 19 Roofwater harvesting system

Roof water collection systems capture rain water from mostly iron sheet roofs and convey this by a gutter to a storage system (see **Fout! Verwijzingsbron niet gevonden.**). In essence this approach is the same for household and communal systems, though the dimensions and materials used vary.

Household systems can be completely constructed from locally available materials. Gutters are often made from bamboo or PVC. The storage systems range from a simple jar to ferro-cement or brick-cement tanks, eventually installed as an underground cistern. In the paragraph on well recharge it is explained that unlined hand-dug wells can serve as rainwater storage as well. The dimensions of the storage system determine the period of use after the rainy season. Even very small roofs usually collect enough water to overflow a small 500 L jar, as most rain falls in extremely short periods (Thomas and Martinson, 2007). Larger storage systems are relatively expensive; the dimensions of the system are a product of the available funds and required performance.

The main advantage of household rainwater harvesting is the fact that water is collected and stored at the location of its usage. Water quality generally meets the standards for drinking water, provided that the system is well operated and maintained (Thomas and Martinson, 2007). It is essential that at the start of each precipitation event, the first 20 L of water is diverted away. This is crucial as the first runoff can contain dust, bird droppings and other contaminations from the roof. There are specific foul-flush devices available to automate this process, which create a more secure and user-friendly system. In polluted areas it is advisable to use additional water treatment methods such as filtration and disinfection (Hatum and Worm, 2006). If stored in a closed container, the quality of clean rainwater can be maintained for about two months (UNEP, 2014b).

The performance of household and communal systems differs considerably. Communal water harvesting initiatives are widespread in Bangladesh, collecting water from the roofs of schools or other institutions. However, the lack of clear ownership and maintenance responsibilities has resulted in extensive failures (Thomas and Martinson, 2007; Ahmed, 2002). Moreover, people tend to have a low level of acceptance for this method, because they have been accustomed to private accesss (of groundwater) in the past. Though groundwater is often contaminated, it has drastically changed common perceptions on water access. Household systems perform much better in the field of water quality, but bring in health risks as the ultimate quality depends strongly on users' investment in cleaning, proper operation and treatment. Moreover, the cost-effectiveness of household rainwater harvesting is extremely low when taking into account the volume of water that is collected. Though the cost-effectiveness of communal systems is much higher than that of household systems, it is still considered by the World Bank (2005) as the only arsenic-mitigation strategy that is not welfare increasing[1].

5.2 Evaporation technologies

Technology information sheet	TR-12

[1] The analysis compares the sum of saved output productivity and foregone medical costs achieved through the reduction of arsenic exposure with the costs of the rainwater harvesting system (World Bank, 2005).

Highlights – These methods are applicable where no feasible alternatives exist for the processing of waters with high dissolved salt concentrations. Several methods exist, but their limited applicability is indicated by their restricted use in Bangladesh.

Thermal distillation is a well known process for water desalination and purification. Conventional thermal distillation processes are inefficient in their energy use, and suffer of high concentrations of brines (i.e., scaling, corrosion). Even where fuel is relatively cheap, its use is limited (Shannon 2008). However, in remote areas and at family or small community level, thermal distillation via solar stills can provide a solution for drinking water, mostly where solar energy is abundant but water quality is poor. This technology is ideal for low capacity and self-reliance water supplying systems since they can produce drinking water based on solar energy only, with no extra energy input.

Impure water is inserted into a sealed container where it is evaporated by the sun heat through clear plastic/glass. In contact with the plastic/glass surface, the water vapour condenses, and pure water drips down the cover and is collected and removed. The pure water vapour condenses on top and drips down to side, where it is collected and removed (Vinoth Kumar and Kasturi Bai (2008)).

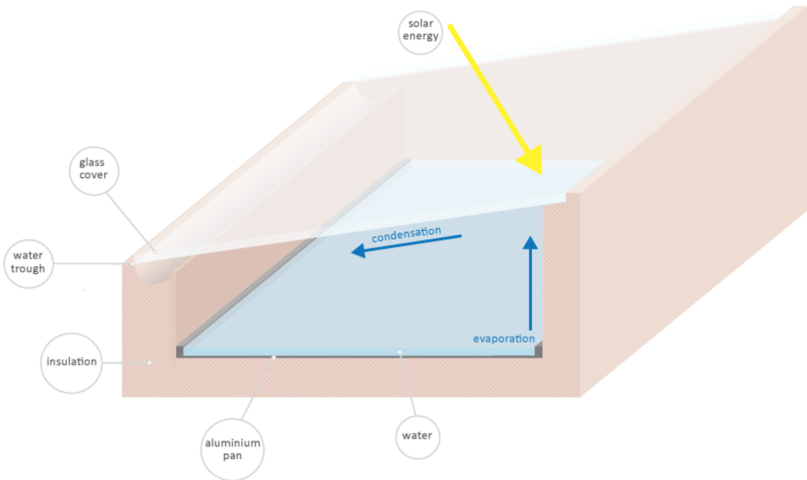

Figure 19 Simple solar still

A schematic diagram of simple solar still is shown in Figure 19. It consists of an insulated black painted container (in this case, an aluminum pan) where raw water stands at shallow depth (few centimeters). A sloping cover of transparent plastic/glass, supported by an appropriate frame, covers the pan and is sealed tightly to minimize vapour leakage. A distillate collector runs along the lower edge of the glass to collect the distillate and to transport it outside the sealed container. The maximum efficiency for a solar still is around 50% as compared to full insulation, although typical efficiencies can be 25% and average production of drinking water remains between 4-8 L/m^2 (CAWST (2011)) when properly built. Single-basin stills have been much studied and their behaviour is well understood. Daily output as a function of solar irradiation is greatest in the early evening when the feed water is still hot but when outside temperatures are falling.

In literature, very few studies have been dealing with solar stills in Bangladesh. Rahman et al. (2001) constructed various solar desalination systems using locally available materials (i.e, clay, bricks, ferrocement, mild steel) and tested them together with the Bangladesh University of Engineering and Technology, both on the roof of the university, and in the field. Maximum yield obtained was quite low (1.5-3 L/(m^2 d)) and so the efficiencies (average 20%). Water costs for 1 year were calculated between USD 0.013/L and USD 0.016/L, depending on the material used for construction.

<u>Photovoltaic panels: sustainable energy utilization in the water sector</u>

At present, the most relevant trend for Bangladeshi water experts is possibly the quick dissemination of photovoltaic (PV) panels worldwide. Unlike, FCUBED and similar evaporation methods, PV panels only power water method installations. (PV panels transform solar light into electric energy.) But while evaporation stills and similar methods tend to have household-scale use only, the modularity of PV panels allows the utilization of solar energy from small-scale household applications to the powering of large treatment facilities. Because of this feature and the fact that operational and maintenance costs of PV panels are negligible, these are increasingly used worldwide. In the Southern provinces of Bangladesh, PV panels are already being used for the powering of small-scale, piped water schemes.

Once a significant local manufacturing and market sector is developed, PV panels can be optimally applied throughout Bangladesh. It is expected that especially rural, remote areas can benefitially make use of this on-site energy generating option. The main advantages of PV panels include:

- Only the purchase and implementation costs are significant; O&M costs are negligible,
- Thereis already a positive global track-record on their applicability in emerging water sectors,
- It can support even community-scale solutions in areas with no or limited power infrastructure,
- A sustainable means on energy supply,
- Current scale-up in manufacturing (worldwide) indicates that purchase costs are likely to further decrease in the near future.

Any utilization should consider the following limitations:

- Depends on the solar conditions (daily hours of sunshine) of the location of use,
- Significant purchase cost implies vulnerability to theft or sabotage,
- Using with already existing water supply facilities may mean that inclusion of a battery or overdesigning is necessary (considering that sunlight can only power during the day hours, but even then with differing efficiency),
- In areas with reliable infrastructure, using electricity form the conventional grid (even diesel) may be a more manageable alternative.

Text box 2 The promise of photovoltaic energy for the Bangladeshi water sector

Wick stills are a promising modification of solar stills. A wick in form of a porous material is placed in contact with the water of the basin. The solar radiation falling on the glass cover transmits through it and reaches the wick surface, where it is absorbed. A part of the energy is utilized for heating the water flowing through the wick due to capillary action. A large amount of heat gets trapped in the still, and transfer of energy occurs from the wick surface to the glass cover and to the ambient air (Manikandan et al. (2013)). The porous material increases the surface area available for heating while the capillary action ensures that small amounts of water are heated more efficiently, increasing the evaporation rate.

Many commercial versions of solar stills can be found on the market, The Waterpyramid® (AQUA-AERO (2014)) for example is an inflated foil structure able to produce up to 350 m^3 of water by solar distillation, while the external surface can be used for rainwater harvesting. The collected/produced water is then safely stored in external tanks. The idea was rewarded by the World Bank with the

Development Marketplace Award in 2006. Another system successfully implemented is the Carocell™ solar desalination/purification technology (FCUBED (2014)). The production of the system is estimated around 5 L/(day m^2) depending on the external temperature and solar radiation, with efficiencies as high as 65%. Single panels are suitable for the essential need of a family, but the design enables multiple panels to be connected together to produce larger quantities of distilled water from a single source. The external surface of the panels can be used for rainwater harvesting. Different actors installed about 800 systems based on this technology in the coastal regions of Bangladesh. Additional 2000 are in the process of installation.

Other commercial versions, at smaller scale, are for example AquaCone™, and Watercone® for smaller production (a few liters per batch).

5.3 Surface water treatment

Technology information sheet	TR-13 TR-14 TR-15

5.3.1 Pond sand filter

Technology information sheet	TR-13

Highlights – Pond Sand Filters combine a cheap and easy construction and operation with a thorough purification process. They are optimal in high-salinity coastal areas where contamination-poor, fresh water ponds – fed by rainwater – are available. Consumption of water should be preceded by a final household disinfection step (e.g. chlorination).

The Pond Sand Filter (PSF) is a special slow sand filter design that is applied primarily in the coastal regions of Bangladesh (UNEP-IETC, 2014a; Jakariya *et al.*, 2005; Ahmed *et al.*, 2002; Ferdausi and Bokland, 2000). This community-scale water supply solution for 50-100 households is typically built next to artificial, fresh water ponds that are fed by rainwater (UNEP-IETC, 2014a). The key reason to apply PSFs is their simple construction and reliable operation. As in case of most slow sand filters, they can be operated at relatively low costs to adequately remove micro- and macro-nutrients, suspended solids (turbidity), heavy metals and taste and smell (Bruni, 2013; Brikké and Bredero, 2003). The average efficient lifetime of a PSF is reportedly around 10 years.

The design of this method comprises one (Figure 20) or two filtration chambers and a smaller storage compartment. In the two chamber version, the first chamber is filled with coconut fibers or brick chips for the removal of coarse particles (UNEP-IETC, 2014a; Ferdausi and Bolkland, 2000, respectively). In the second chamber, a slow sand filter unit with a sand medium (fine sand and coarse aggregate layers) is placed on a drainage plate. This filter unit removes impurities, reduces turbidity and the biofilm grown on the particles in the upper layer of the filter removes organic contamination. At locations with high turbidity, roughing filters were added to precede the PSF unit.

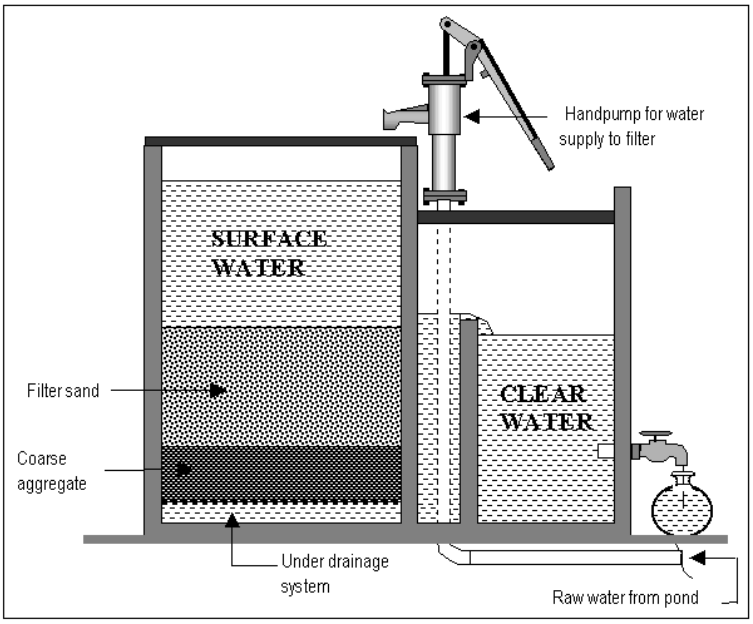

Figure 20 Schematic drawing of a Pond Sand Filter. Source: Ahmed et al. (2002)

For the operation of a PSF unit, the pondwater is pumped manually onto the filter (Ahmed et al., 2002). The filtrate is readily available for the user. Periodic maintenance of the PSF is required because of the solid particle and organic load on the filter. Especially the upper part of the filter medium can be clogged easily. The growing resistance to water permeation reduces the discharge rate of the unit, but this problem can be temporarily aided by increasing the level of the water above the filter. Ultimately, the filter does require regular cleaning or the replacement of the upper sand filter zone. The cleaning can be achieved with two workers in 45 mintues.

A large number of these filters were implemented in Bangladesh in the last three decades. According to Ahmed et al. (2002), a DPHE programme realized 3,170 until 2000. The earliest implementaitons are suggested in the southern regions of Bangladesh. 90 PSFs are reported to have been built in Dacope thana in 1984 and 24 were built in Kaliganj thana in 1993-1994 (UNEP-IETC, 2014a). Most of these filters are not in operation any more. Reported reasons of failure include low water output and difficulties in the backwashing and restoring of filter media (Ahmed et al., 2002). Ownership conflicts of the source ponds were also reportedly amongst the key reasons of failure. Pond owners tended to neglect arrangements for preserving water quality and introduced fish cultures in the water source. The accompanying organic load meant that the PSF effluent was not suitable for drinking any more.

The PSF is still a suitable and popular method for Bangladeshi use. Since 2004, the AsMat programme is reported to have implemented several PSF units (Jakariya *et al.*, 2005) and DPHE offers technical assistance for the construction of such installations throughout Bangladesh.

5.3.2 Disinfection

Disinfection treatments are normally executed in combination with coagulation, sedimentation and filtration steps and are primarily used for fresh, surface water.

5.3.2.1 UV treatment

Technology information sheet	TR-14

Highlights – UV treatment is a simple method for disinfection that is affordable for centralized treatment, e.g. in rural piped water schemes.

Ultraviolet (UV) disinfection of drinking water is used in small water treatment facilities and since recently it has become available for use on household level (CAWST, 2009). The costs are relatively low, though it exceeds that of chlorination.

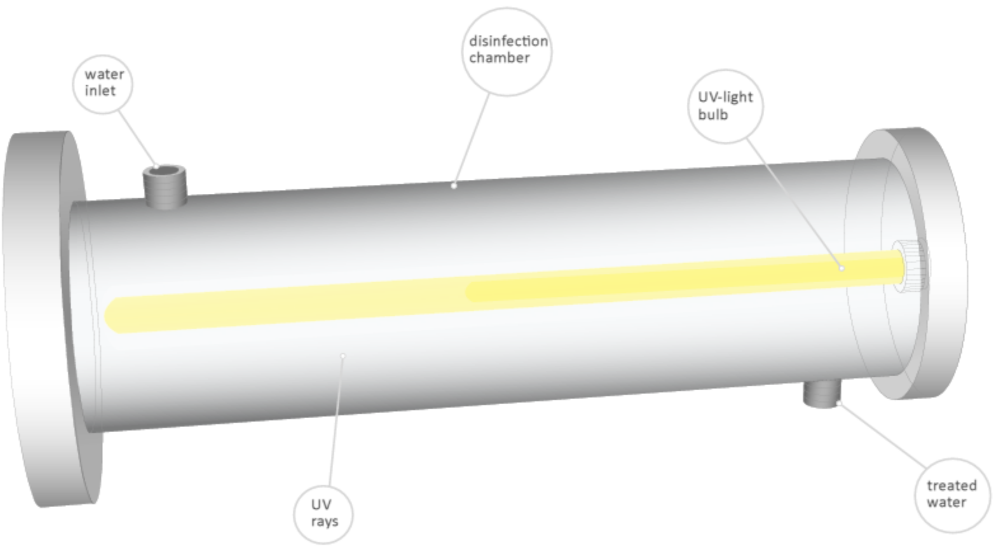

Figure 21 UV disinfection device

During the process, the water flows through a pipeline where it is exposed to a low-pressure UV-C bulb emitting light with wave lengths between 180 and 320 nm. UV light in this range damages the DNA of micro-organisms, making replication impossible. It also functions as a catalyst in oxidation reactions in case of conjunctive application with ozone. UV treatment is an effective method to inactivate bacteria and viruses, as well as protozoa, fungi and algae (WHO, 2006).

As UV radiation cannot penetrate through turbid water or solid particles, it should be used in the last stage of a water treatment system, or at least after a pre-filtration step. Another concern is that it does not result in residual disinfection, which implies that a secondary disinfection method is needed in case water is not consumed directly (Wagenet, 2004).

5.3.2.2 Chlorination

Technology information sheet	TR-15

Highlights – Chlorination is one of the most efficient methods to tackle (pathogenic) contaminations of surface waters. It is easy to apply both manually and with (semi-)automated dosign devices. Limited use in Bangladesh is indicated from literature and experts, despite that it is an optimal, final method for the provision of safe water for everyone.

The historic decrease in mortality due to waterborne diseases in developed countries can be mainly attributed to the use of chlorination (Galal-Gorchev, 1996). Nowadays it remains the most common water disinfection method globally, being a near guarantee to safe drinking water if applied correctly.

The essential chemical process that makes chlorination a good disinfection method is the formation of hypochlorous acid (HOCl) and hypochlorite ion (OCl^-), once chlorine dissolves in water. Subsequently micro-organisms are killed as they react through oxidisation with the hypochlorous acid. It is this process that is responsible for disinfection, irrespective of the particular form of chlorine that is used. Apart from being a microbial disinfection method, the chlorine oxidant also removes specific chemicals, e.g. by decomposing particular pesticides or by forming insoluble products from dissolved elements (WHO, 2006).

Chlorination is used on both household level and in communal treatment plants to disinfect water from pathogens, and from bacteria in particular. It can be applied in solution (bleach, WATA, WaterGuard), powder (bleaching powder, PUR), tablet (NaDCC) or in case of communal treatment it can be injected as a gaseous form. The dissolving process at household level takes about thirty minutes before the water is potable. The minimum target concentration of chlorine at the point of usage is 0.2 mg/litre, but this vlue should be raised to 0.5 mg/L in situations of higher risk.

It is important to note that apart from the concentration and contact time, the efficiency of chlorine disinfection is highly influenced by the pH and turbidity of the water. Especially micro-organisms within flocks or particles often escape from the oxidation process. Therefore, chlorination should be applied at the end of a water treatment system that conditions the water for effective disinfection (Galal-Gorchev, 1996).

In Bangladesh, like in many other countries, the adoption of chlorination at household level has been limited due to the taste and odour of the water. Most people taste or smell chlorine at concentrations well below the health based target of 0.5 mg/L, and therefore reject its use or apply quantities that are insufficient. Experiments with a granular activated carbon (GAC) filter proved to effectively remove the chlorine prior to drinking and significantly increased satisfaction among users

(Flanagan et al., 2013). Concerns about the health risk of by-products from chlorination are generally discarded by scientists, as the risk from microbial pathogens is considered to be much greater (Galal-Gorchev, 1996).

5.3.3 HWTS

Technology information sheet	TR-16

5.3.3.1 Coagulation-flocculation

Coagulation refers to the chemical reaction in which a coagulant makes fine materials as colloids join into small aggregates. The formed aggregates subsequently attract further suspended matters. Flocculation concerns the mixing process after the initiated coagulation, to stimulate settling of the aggregates (WHO, 1996). Coagulation or flocculation can be applied to remove fine suspended matter from drinking water. This process should be succeeded by a filtration step in order to remove the formed flocs from the water. The principle is applied in both communal (section 4.2.1) and household-level treatment processes. If applied at the household, this provides a medium labor-intensive method that can achieve efficient removal of several contaminants that are typical for surface water.

There is a range of chemical coagulants, the most common being aluminium sulphate, poly-aluminium chloride and ferric sulphate. Next to that there are natural products that can act as a coagulant, like moringa seeds, prickly pear and fava beans (CAWST, 2012). In Bangladesh, this purification method is applied in some of the filters described in chapter 4.

5.3.3.2 Boiling

Technology information sheet	TR-16

Highlights – Boiling is a safe and easy way to disinfect water, but only for drinking and cooking purposes.

Boiling is undeniably the most widespread applied disinfection method worldwide. It is very efficient against microorganisms. Boiling water for at least 1 minute can already ensure safe biological conditions. Because of the fuel required for the cooking of water, it can only be recommended for the provision of drinking and cooking water. Considering the conventional household use of this method, no specific training is required. However, the energy need (possibly from charcoal, wood) may contribute to an unsustainable practice of deforestation.

5.3.3.3 Ceramic pot filter

Technology information sheet	TR-17

Highlights – Ceramic pot filters are relatively reliable devices for the removal of surface water-related cotaminations at the household level. The pots are affordable for all, and more importantly they have been demonstrated to be producible locally. This feature can contribute to widespread availability and increase in local livelihood.

The 2 main types of ceramic filters for water filtration are pot filters and candle filters. The ceramic pot filter is a combination of a filter and storage. It can improve the quality of drinking water where the water is contaminated with bacteria and solids. An advantage of the pot filter over the candle filter is its possibility for local production by local enterprises, providing the materials for fabrication are locally available. The candle filter on the other hand is less vulnerable for breaking and can be more easily transported.

The pot filter method is based on the special production that can produce a porous ceramic pot. The pot filter becomes porous when the clay is mixed with materials such as rice husk or sawdust. After the shaping of the pot it is heated until the husk or dust burns and leaves behind very fine pores in the pot. This porous structure allows the seeping of the water, but can retain most of the bacteries. To increase pathogen removal, the ceramic pot is also treated with a colloidal silver solution that acts as a bactostatic agent (van der Laan *et al.*, 2014).

Ceramic filters are widely used in places where need to people resort to unsafe sources such as open water and open wells. The pot can hold about 8 L of water and transmit 1-2 L/h. If the pot is filled regularly it can provide enough water for a household with up to 40 L/day.

5.4 Natural engineered systems

Technology information sheet	SD-06 TR-18 TR-19

The potential of natural engineered systems has been explored in Europe for many decades (van der Kooij, 1985; van Beek, 1985; Appelo and de Vet, 2003; Schmidt et al., 2003; de Vet at al., 2010). These systems have been proven to be a sustainable addition to conventional drinking water treatment. A “natural” system treats the water either vegetative-based (constructed wetlands) or soil-based. This section focuses only on water treatment through soil passage, utilizing the subsurface as a naturally available sand filter. (In)organic compounds are removed from the water through processes of filtration, adsorption, oxidation and biodegradation. Smart engineering can improve the removal efficacies and expand the lifespan of such a natural drinking water treatment system. Examples of natural engineered systems are (river) bank filtration, managed aquifer recharge and artificial recharge and recovery.

5.4.1 Well recharge

Well reacharge is a rainwater harvesting method. It offer the cheapest way to store large quantities of rainwater in the shallow groundwater layer. Instead of using a jar or tank, the collected rain is conveyed into a hand-dug well, where the existing (often saline) groundwater is replaced by fresh rainwater seepage (see Figure 22). This process called backwashing creates a fresh water zone around the well, which is very valuable in areas where groundwater is affected by salinity or arsenic. The method is most effective in sandy and loamy soils and if applied to multiple wells it can restrain saline water intrusion in coastal zones as well. The approach could also serve as artificial recharge to prevent dropping groundwater levels, though it cannot compensate for the effects of widespread aquifer overexploitation (Thomas and Martinson, 2007).

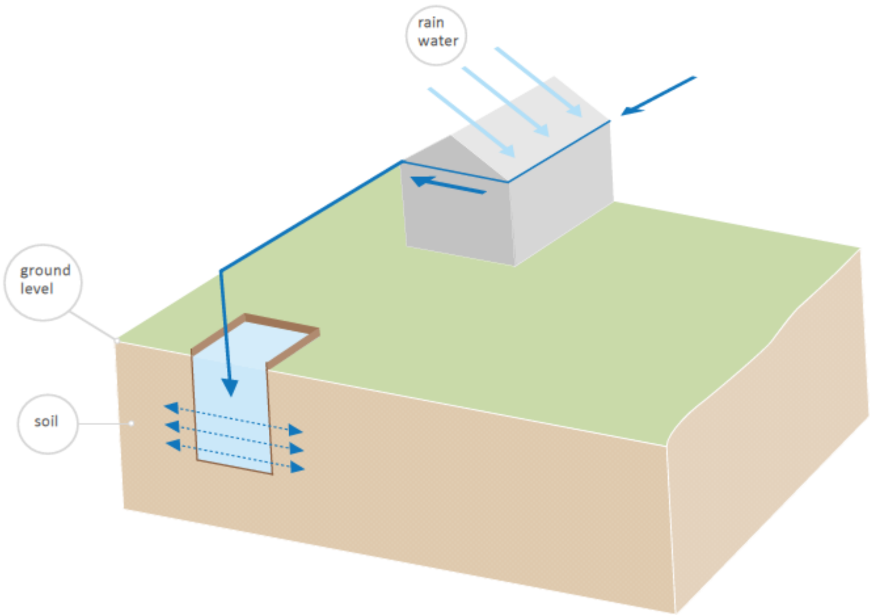

Figure 22 Groundwater backwashing as a result of well recharge

The well recharge method through rainwater harvesting has been applied on a large scale in the Indian Mazhapolima programme, by which more than 8000 recharge units have been implemented in the Thrissur district. The programme was launched by the district authorities in 2008 and has become an official government scheme to combat the effects of climate change since. The implementation was executed by the authorities in participation with private agencies and beneficiaries. Users were actively involved by large-scale community education and consultation efforts. The impact in the coastal and midland regions has been impressive[2], as groundwater levels have risen, salinity levels decreased, and heath indicators improved. However, the approach could not successfully control bacteriological contaminations, which highlights the need for additional filtration systems and periodic disinfection (CWRDM, 2013). Apart from the technical effects, the participative approach of the programme also led to reduced public spending and strengthened decentralisation of drinking water supply. The intervention is now turning into a model to deal with drinking water scarcity throughout the Kerala region (ibid, 2013). As coastal zones in Bangladesh face similar salinity problems and additional arsenic contamination, the lessons learnt in the Mazhapolima programme could be a valuable asset in Bangladeshi water supply strategies.

5.4.2 Infiltration galleries

Technology information sheet	TR-18

[2] In highland regions the effects were only marginal (CWRDM, 2013).

Highlights – Efficient surface water method already widespread in Bangladesh. The key design restriction is the availability of contamination-free source water. No complex parts in the method, technical resilience may be limited if sludging of the infiltration pipes results in severe reduction in water discharge.

Infiltration galleries are surface water utilizing constructions that are often deployed complimentary to other water supply options (WaterAid Bangladesh, 2006; WHO, 2002). Their use strongly depends on whether they can produce water without interruptions in the driest months of the year. Galleries normally consist of drain-type pipes and collector wells. The pipelines are perforated or open joint pipes or drains that are installed under the minimum water table of surface waters (ponds or streams). Diameter of screen is typically 75-300 mm allowing a water yield of 15 L/min/m. The pipelines are advised to be placed at 1.5 m below the riverbed in order to withstand changes in water level throughout the whole year. Length of the pipeline is flexible and installations range from a few meters (to aid water collection of a spring box) to several km's in larger rivers.

Collective wells ensure the collection of abstractable water from the infiltration gallery. Construction quality is equally important at this unit as the washed out debris accumulates together with the water. Pipe into the collective well needs to be built with a slope that allows a water velocity of 0.5-1.0 m/s (IRC, …). This velocity range in the pipe is necessary to wash out of debris into the well. Removal of this debris from the collective well and the pipeline is important to prevent clogging of the system.

The quality of the gallery designs depends primarily on its location (Schmidt *et al.*, 2003). The design requires permeable soils that allow penetration of the above-lying water, but hold back the debris and most of the coarse solid particles. In many cases, optimal soils are unavailable, necessitating the application of a gravel pack of one or more layers around the drain pipes to improve the filtering and draining capacity of the gallery. In is not feasible to implement these designs where a hard bedrock forms the river or pond bed.

Type of gallery depends on the chosen water source (pond or stream) and the size of the installation (WaterAid Bangladesh, 2006). The potential water source also needs to be relatively free of contamination. Infiltration wells are vulnerable to surface water impurities. The probable contaminations of surface waters include pathogens and organic load; possibly pesticides or chemicals in agro-industrial areas. The installation needs to be located upstream from a settlement (especially latrines) or agricultural activities, as these are also key contributors to organic and pathogenic loads (Schmidt et al., 2003). A fish culture is prohibitive to the safe use of the water source. WaterAid Bangladesh advises a quality control procedure during the siting, and annually twice in the operational phase (once in the rainy and once in the dry season). Their design criteria for water quality include a maximum faecal coliform concentration of 10 fc/100 ml and a turbidity limit of 10 NTU.

The construction of an infiltration gallery is optimally done at the end of the dry season in Bangladesh (Nissen-Petersen, …). As the water level in the river or pond is lowest, not only the logistics and constructions is made simpler, but the height of the gallery can be better determined as well. Construction may occur with the active (labor) contribution of the beneficiaries, requiring training and supervision from the the executing organization. The management of the installation is typically left with a local CBO or similar stakeholder. The financing is often in a cost sharing construction where future users would either deposit the required contribution prior to the construction, or they are paying after the implementation (usualy in installments).

In the past, several units were constructed in the coastal areas of Bangladesh in order to make use of surface waters with low salt concentrations (Ahmed, 2002). Water quality was often sub-optimal, necessitating an additional disinfection step at the household. Accumulation of sludge in the infiltration pipes and wells were also reducing the efficiency of this method.

5.4.3 Riverbank filtration

Technology information sheet	TR-19

Highlights – In this method, abstraction from surface water sources is achieved in combination with a slow, bank filtration. Already applied in developing countries with success. Bangladeshi potential is high as it requires limited technological complexity and filtration has been demonstrated to be efficient in the pathogenic and turbidity removal of the source water.

Bank filtration (Figure 23) abstracts water from the subsurface near a surface water body like a river or a lake at a distance of several meters up to a few hundred meters. A significant amount (>80%) of the abstracted water consists of infiltrated river water, depending on the hydrogeological situation and the placement of the wells (van der Kooij, 1985). In Germany, more than 300 water works use bank filtration (16% of German water supply) and roughly 50 plants are based on artificial groundwater recharge. In particular, major water suppliers often use artificial recharge in drinking water production. The retention time in both techniques may vary from 5 to 100 days and more (Schmidt et al., 2003). There are various set-ups for bank filtration, depending on the hydrological and geohydrological situation and the need to increase or decrease the mixing of the abstracted surface water with groundwater. In India, there has been a history of using bank filtration, although scientific documentation of studies is needed to fully realize the potential of this method (Sandhu et al., 2011).

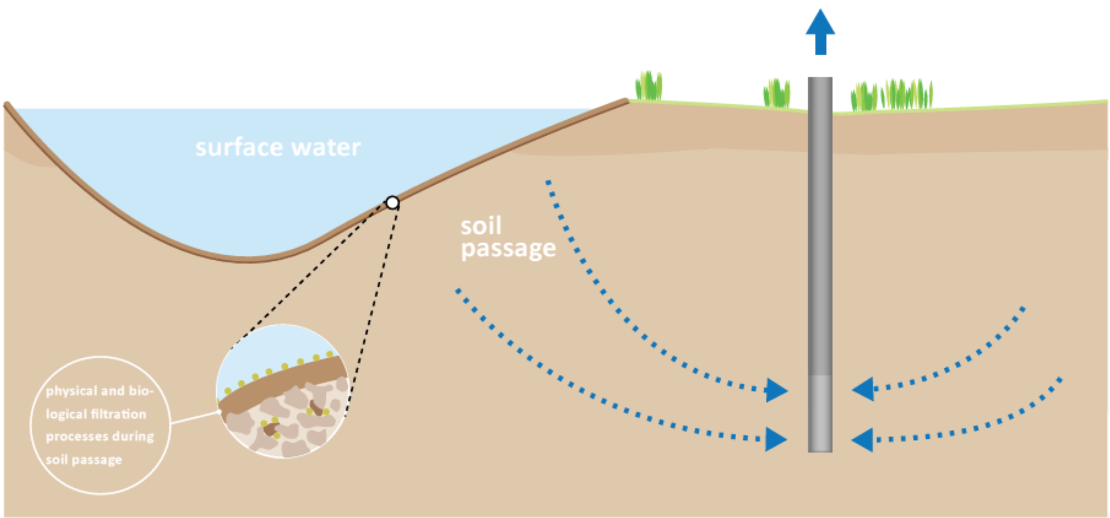

Figure 23 Riverbank filtration (RBF)

Initially bank filtration was designed and operated to achieve a minimum residence time of 60 days to assure microbial safe water quality (van der Kooij, 1985). In the past decades the mechanisms and the efficacy of microbial reduction by soil passage have been studied to better determine the required residence time (Yao et al., 1971; KIWA, 1997; Schijven, 2001; Tufenkji and Elimelech, 2004; Medema and Stuyfzand 2002; Smeets et al., 2009). Large organisms such as helminths (eggs) can be removed by straining, when the organism is larger than the pores. Small organisms such as protozoa (Cryptosporidium, Giardia), bacteria (E. coli , Campylobacter, Vibrio cholerae, Salmonella typhi) and viruses (norovirus, adenovirus, poliovirus) are removed by retention in the soil and subsequent die-off or inactivation. These organisms are retained by attachment to soil particles. The residence time of these organisms in the soil is influenced by various factors such as flow rate, distance to the well, water quality parameters, soil particle size and material, that affects the process of retention in the soil. The level of inactivation that takes place during this residence time mainly depends on the type of organism and the temperature. Protozoan (oo)cysts, some bacterial spores and viruses can remain infective for months to years, whereas free living bacteria can be inactivated within days to weeks. The complex interactions make it impossible to accurately predict pathogen reduction at a specific site. Results from various experiments with bank filtration, basin recharge and deep well injection were collected by Medema and Stuyfzand (2002). Bank filtration generally achieved 4 log or more reduction of protozoa, bacteria and viruses. Thus it was concluded that “most of the aquifer recharge or river bank filtration systems achieved hygienically safe water for drinking water supply. Critical situations may arise, however, in the following cases: (a) where infiltration intensities are extremely high and travel times are short, like in river bank filtration systems drawing from gravel aquifers also during flood events; and (b) where the recollection system may receive inputs through short circuits or imperfections in air and watertight constructions”. Systems can avert the risk of insufficient treatment during floods by putting the wells closest to the river bank out of operation.

Infiltration also affects the chemical quality of the water. Generally some mixing with groundwater takes place, causing dilution of contaminants. Due to residence time distribution, shock loads and (seasonal) variations of contaminants in the infiltrating water are dampened, resulting in a more stable water quality. When actively controlled, infiltration could even be shut down during periods of high contaminant loads. However, natural infiltration of surface water will continue, and thus not completely preventing contamination of the produced water. Heavy metals can be removed at levels ranging from 0 to 94%. Arsenic removal up to 93% has been observed (Schmidt et al., 2003). Ammonium can be transferred to nitrate in aerobic conditions. Nitrate is denitrified when conditions become anaerobic, over 50% of the organic substances can be removed. These processes result in more biologically stable water. Surface water can be contaminated by agriculture or industry upstream. Removal of substances such as pharmaceuticals is known to vary substantially (Drewes et al., 2003). Soil passage, either through bank filtration or artificial recharge, can have several benefits over direct use of surface water or groundwater (Text Box 3).

Bank filtration versus surface water

+ Better quality than surface water, especially microbial
+ More stable quality (dampening quality changes in river)
+ Some storage
+ Better protected against contamination
- Investment and exploitation cost
- Risk of clogging
- Some effect on groundwater level

Bank filtration versus ground water

+ Avoid (natural) contaminants like arsenic, nitrate and fluoride?
+ Less impact on the water table?
+ No need for further treatment (aeration, iron removal)
- Some safety risk
- More vulnerable to contaminants in surface water

Artificial recharge

+ No need for deep wells
+ Use alternative water sources (no groundwater depletion)
+ Improve water quality (especially microbial)
+ Protected storage of water
+ Avoid (natural) contaminants like arsenic, nitrate and fluoride
+ Some control on infiltrated water quality is possible

Points of attention:

- Sufficient travel time and distance
- Homogeneous soil (sand) no cracks/coarse layers
- Prevent infiltration near the abstraction point
- Maintenance for clogging (particles and iron oxidation)
- Pre- and post treatment needed?

Text Box 3 Advantages and disadvantages of drinking water treatment through soil passage

5.4.4 Artificial and managed recharge

Technology information sheet	SD-06

Highlights – This method group mitigates arsenic- and salt problems through the introduction of rain or surface water into the shallow underground aquifers. It is especially suitable for the reduction of salinity problems in the South of Bangladesh. Local hydrogeological conditions of the upper soild can greatly influence its effectivity and its implemenhtaiton should proceed with additional research in oder to offer a reliable solution.

The principle of artificial and managed recharge is similar to bank filtration, as water in either infiltrated (Managed Aquifer Recharge, MAR) or injected (Artificial Recharge and Recovery, ARR) into the subsurface (see section 5.1.1.2 for the rainwater option). Figure 24 depicts the difference between MAR and ARR. In both cases, surface or rainwater is used to create subsurface storage of fresh water. The stored water is recovered with a tube well, after sufficient retention time in the subsurface. Artificial and managed recharge is most often applied either to prevent salt water intrusion in coastal regions (e.g., Dutch dunes) or to store surplus rainwater. Advantages of subsurface rainwater storage over above-ground storage include the prevention of evaporation and degradation of microbial water quality. Disadvantages of subsurface rainwater water storage are the loss of fresh rainwater through mixing the original groundwater and the uncertainty of dissolution soil-based contaminants (e.g., arsenic). Monitoring of a subsurface system is more challenging than above ground and hydrological and geochemical modeling is often required.

In case ARR in practiced, the source water is injected into the subsurface through a tube well. In such a design it is essential to have pre-treatment of your surface water, because unlike during MAR and bank filtration, the water quality is not improved during soil passage – or through cake filtration through the bank/lake schmutzdecke. In Bangladesh, ARR is practiced in the coastal areas to store rain- and surface water in brackish aquifers (Acacia, 2011). Initial results of this action research, jointly with Dhaka University, UNICEF and DPHE, are promising, although results vary widely per site.

During MAR, the water infiltrates downwards to the recharge aquifers, requiring that there is a sandy, permeable soil. In many regions in Bangladesh a clay layer separates the upper groundwater table and the safer, shallow aquifer. In combination with high temperatures (= evaporation) this approach may not be very effective. For MAR it is also essential to address the issue of clogging, as the bottom of the infiltration basin, lake or pond may clog during use (Bouwer, 2002). Regular cleaning of the bed by removal of the top layer (schmutzdecke) can reduce problems with clogging. The schmutzdecke also has a major advantage, as like with bank filtation and slow sand filtration, this microbial active layer contributes significantly to the removal efficiency of the system.

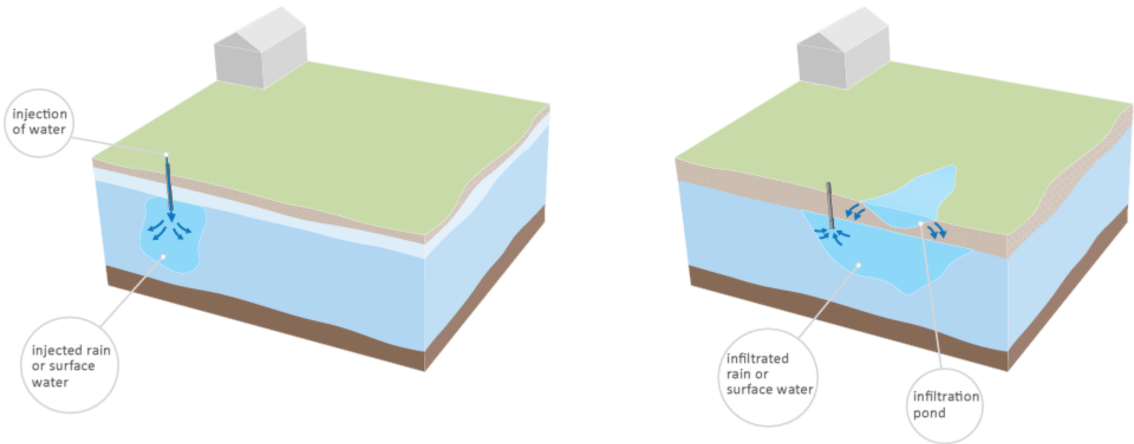

Figure 24 Artificial Recharge and Recovery (ARR) and Managed Aquifer Recharge (MAR)

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6 The ASTRA decision-support tool

6.1 Practical execution of the eligibility screening

The ASTRA tool can be used as a compendium of method descriptions and also as a decision-support tool for the quick selection of potentially implementable water supply methods for a real setting.

6.1.1 When using ASTRA for the first time

As an off-line tool, the matching of the context factors with the eligibility matrices is done manually, by comparing a method's capabilities (demonstrated by the matrices) per factor. In the online tool, the screening factors can be inserted in the checkboxes of the screening panel (left column of the tool). Once all relevant options are chosen, the 'Add criteria' button will trigger an automated screening process. The output of the screening process is the highlighting of the applicability of each method: eligible in *green*, partially eligible in *yellow* and non-appropriate in *red*, respectively.

The information provided on each method can be viewed by visiting the site astradst.info and

1. Clicking on the '*Proceed to the ASTRA tool*' button on the top of the page. (Note, that a detailed manual is present on the introduction page.)
2. On the appearing page, '*View info*' should be applied below the interesting methods.
3. Once the basic information is viewed, Additional information can be viewed by scrolling down on the window for links on (i) Bangladeshi organizations that implement or use the method or (ii) literary resources.

Methods that fit one or more criteria of a certain situation or project context can be identified by viewing which methods are forwarded by the tool as

- *Fully functional* (logo's become *green*).
- *Functional but with restrictions* (logo's become *yellow*).
- *Not functional / not recommended* (logo's become *red*).
- *Not relevant*, meaning that the selection criteria does not apply for the functionality of that method (logo's remain *white*).

1. Once the methods are checked the reasons of restictions or non functionality can be confirmed by clicking on the '*View info*' button of a method. In the section '*Relevant remarks*' the key reason(s) of limitation are given. If the screening needs to be redone, then the button '*Clear criteria*' should be used, before the new selection can be made.
2. When ready with the viewing of potential methods, the selection box in the up-left corner of their logo's should be activated in order to mark them for selection.
3. The button '*Add technologies*'should be used to place te potential methods to the section '*Selected Technologies*'.
4. In the section '*Selected technologies*' moving or removing any of the chosen option can be done by clicking on the '<', '>' or '*x*' buttons under the logo, respectively.
5. Finally, the output document can be created by clicking on '*Create PDF*' above the selection bar. Note, that in its digital form, the links in the pdf file still work!

By completing this procedure, the final pdf file can be applied to with other project stakeholders to discuss the selection. It is important to remember, that the tool can only offer information on what is *typically true* for the included methods. In specific cases, some of the actual information may deviate from the described functionality. To offer an example, small-scale piped water networks often have a high user preference. However, regardless of income level or geography, some community's may have a different opinion. So it is important to keep in mind that the tool is only useful when viewed with a critical focus of the actual project. To incorporate such deviations between the proposed and the actual situation, even methods marked as yellow (or even red) can be marked as preferred choices.

6.1.2 How to integrate mitigation approaches into the screening process

In a Bangladeshi water project, arsenic- and salt-free water is typically provided through one or more of the following three basic principles:

- Direct abstraction of safe groundwater;
- Treatment of contaminated (ground)water; and
- Alternative, non-groundwater water supply, using rain or surface water.

So when trying a potential water supply situation needs to be built, the first consideration can be the selection of the most optimal mitigation approach. Once it is established whether direct abstraction, treated water or a non-groundwater option is the optimal mitigation approach, users can concentrate on the corresponding methods and their assessment.

While water users typically prefer direct groundwater abstraction in Bangladesh, it is certainly not the most sustainable way of water use. An alternative to the prior identification of a potential mitigation option is to start with identification of optimal solutions, by leaving the criterion '*Water source*' open. This will not only leave ecologically more sustainable rainwater solutions in the selection, but also other – often neglected – alternatives. Even if it may seem ri sky to recommend less known methods to project partners, it is often a better option than to automatically resort to the use of the conventional groundwater-deep tube-well solution.

The ASTRA tool supports a very rapid screening, so it is recommended to experiment with several different scenarios before aggregating a pdf report from the potential methods for a given project situation.

6.2 Definitions of the screening criteria and options

In the following, the context factors and the included options are defined to aid tool users on method applicability. In the online tool, these definitions are incorporated in the form of pop-up windows.

6.2.1.1 Water source

This screening factor defines the required water source for the intended water supply project. It is important to note, that water source is a key determiner of all other factors that influence method selection. Therefore, it is advisable to view and discuss this factor in more detail than any factors in the inventory. Although the selection of this factor may seem self evident, it is proposed that viability of multiple sources for one project is evaluated. An example: the combining of rainwater and groundwater as a source can reduce the risk of over-abstraction from the local aquifers. If more than one source is chosen, then their eligibility needs to be determined separately.

Table 7 **Options and definitions for the screening factor 'Water source'**

Name of category	Explanation in pop-up window

Name of category	Explanation in pop-up window
Rainwater	Rainwater technologies reduce load on ground- and surface water sources and are ecologically sustainable. A basic requirement to most of these technologies is the availability of at least 200 mm rainfall per annum in the implementation area. When choosing this option, all rainwater-related methods become eligible.
Surface water	In general, surface water exploitation is cheaper than groundwater or rainwater methods. However, surface water bodies are most often expected to have anthropogenic contaminations. By choosing 'Surface water', all surface - still and streaming - water methods become eligible.
Brackish water	This option makes all salt-mitigating options eligible, including related surface and groundwater supplying or treating technologies.
Groundwater	Groundwater technologies require increased financing for well construction and maintenance. A key advantage of these technologies tends to be the reliable water supply combined with limited arsenic-, salt- and pathogenic contaminations. When selecting this option, all salt-mitigating options become eligible.

6.2.1.2 Removal

This factor defines which contamination needs to be removed from the source water. Selection in this screening factor can be omitted, when the available water source contains both contaminations. No other contamination is included as option. Removal of pathogenic, heavy metals or other contaminations is described in the technology information sheet of each specific method.

Table 8 **Options and definitions for the screening factor 'Removal'**

Name of category	Explanation in pop-up window
Arsenic	Link: WHO water quality guidelines
Salts	Link: WHO water quality guidelines

6.2.1.3 Location

Location is one of the defining factors of the settlement type. Its importance has to do with the fact that settlement type and size can give a rough indication of available infrastructure and space limitations. It is of relevance in most water management stages.

Table 9 **Options and definitions for the screening option 'Location'**

Name of category	Explanation in pop-up window
Densely populated urban	Central, business district type settlement area. Can be characterized as a high population density area with a considerable commuting public, limited availability of space, but a relatively high level of infrastructure.
Densely populated, low-income urban	Urban type, low-income settlements. These areas can be characterized by high to very high population densities. As a consequence, space availability is very restricted and little to no infrastructure is available.
Moderately populated urban	Moderate population density areas with limited infrastructure. The characteristic inhabitant has middle- to high-income.
Peri-urban/rural	Moderately populated, low-income settlements. Space availability for the construction of water points may be restricted, but it is not likely. Average income levels tend to be low, requiring robust but affordable water supply

	solutions.
Rural/remote	Can be defined as asset-poor, remote settlements with limited to no infrastructure. This implies no spatial limitations for the implementation of water projects. A key consideration for water supply is the limited possibility for central monitoring and restricted supply of parts or chemicals.

6.2.1.4 Zone in Bangladesh

This factor co-defines the specific geo-hydrological zone within Bangladesh to enable further limiting of eligble methods for selection.

Table 10 **Options and definitions for the screening option 'Zone in Bangladesh'**

Name of category	Explanation in pop-up window
Flood plain	Areas near to rivers with high risk of flooding during the wet season
Low water table area	Areas with a low ground water table, especially during the dry season
Coastal zone	Areas near to the sea, with high risk of saline intrusion
Low lying area / basin	Low lying areas (geological depression) with high risk of flooding
Hilly region	High lying areas with often extreme weather conditions (both drought and rainfall)

6.2.1.5 Scale of implementation

This is an important but not often researched aspect of method implementation. It stands for the size of the dissemination project, e.i. at what geographical or socio-economic level would a water method be introduced. To offer an example, handpumps are often implemented regionally, because at this scale it is meaningful to integrate maintenance issues in the form of workshops. Scale of implementation defines not only technological issues. Especially when implementing a novel method for water provision, the scale of implementation can also support or hinder the level of embedding and marketability.

Table 11 **Options and definitions for the screening option 'Scale of implementation'**

Name of category	Explanation in pop-up window
Household	No importance of widespread implementation.
Small community	Implementation needs to involve the whole community.
School or institution	Implementation optimal per institution.
Regional	Implementation needs to consider a large, at least regional scope.

6.2.1.6 Preferred level of water delivery

This factor determines the preferred level of water servicing in a water project. This factor determines whether centralized of decentralized methods become eligible.

Table 12 **Options and definitions for the screening option 'Preferred level of delivery'**

Name of category	Explanation in pop-up window
Household	Water supply intended for one household or 3-6 users per facility or device.
Shared	Water supply intended for 2-5 households or 6-30 users per facility or device.
Small community	Water supply intended for more than 5 households or 30-300 users per facility.
School or institution	Water supply intended for one (public) institute per facility.
Large user group	Water supply intended for one household or 300+ users per facility. Includes

	highly centralized urban supply or treatment technologies.

6.2.1.7 Preferred management level

Water projects need to consider the optimal level of facility managing in the project area. Even with household-level water supply a central management may increase level of system reliability. Therefore, this factor aids the screening of technologies based on their optimal managing (operation and maintenance) level.

Table 13 Options and definitions for the screening option 'Preferred management level'

Name of category	Explanation in pop-up window
Household	Selects technologies that can be optimally operated and maintained at the household-level.
Shared	Selects technologies that can be optimally operated and maintained at a level of 2-5 households.
Small community	Selects technologies that can be optimally operated and maintained at a community level.
Municipal	Selects technologies that can be optimally operated and maintained centrally at municipal level.

6.2.1.8 Status in Bangladesh

This factor indicates how widespread a method is in Bangladesh.

Table 14 Options and definitions for the screening option 'Status in Bangladesh'

Name of category	Explanation in pop-up window
Widespread	This option selects typical water supply or treatment methods in Bangladesh.
Known	This option selects water methods that have been tried but not upscaled in Bangladesh.
Little known	This option selects methods that are represented only by a small number of installations.
Unknown	This option selects methods that are successfully applied only outside of Bangladesh.

6.2.1.9 System sophistication

Technology-intensive solutions offer high efficiency at often higher costs, while labor-intensive methods are suitable where part supply is scarce and conditions require much flexibility from a water technology. Implying local infrastructure and availability of skilled labor, this screening option can help sorting out the optimal level of technological sophistication.

Table 15 Options and definitions for the screening option 'System sophistication'

Name of category	Explanation in pop-up window
Labor-intensive	Contains labor intensive technologies with very limited use of machinery. In general, all technologies with considerable power use are excluded. Most suitable for areas with little to no industry and limited to no skilled labor.
Intermediate	Makes all technologies eligible that contain features of both labor- and technology-intensive categories.
Technology-intensive	Contains technology intensive solutions with restricted to no application of manual labor. Most suitable in areas with considerable technological

	advancement.

6.2.1.10 Ground formation

In-depth knowledge on the soil composition is important to define well methods. This is one of the most complex issues in obtaining water. When groundwater is preferred as the main water source, project participants need to involve geohydrology experts to analyze their ground formation. Of course, often some knowledge exists already on the soil quality, but ill-prepared borehole constructions can cause a fast increase in costs of water supply projects.

Table 16 **Options and definitions for the screening option 'Ground formation'**

Name of category	Explanation in pop-up window
Sand & gravel	Weak cohesive sand and silt gravel soils. A loose, often topsoil formation that is easy to dig and drill.
Clay formations	Soft and stiff clay(ey) ground formations.
Compacted formations	Compacted sediment and consolidated rock formations.
Soft weathered rock	Hard, physically or chemically weathered (sub-)soil rock formations.
Bedrock	Unweathered, basement rock formations. Very hard, unweathered bedrock type (sub-)soils.

6.2.1.11 Well depth

This feature determines the type of wells applicable.

Table 17 **Options and definitions for the screening option 'Well depth'**

Name of category	Explanation in pop-up window
Not required	No well is required in the water project.
0-8 m	This option selects shallow wells and surface water intake.
8-15 m	This option selects shallow wells and surface water intake in the lifting range of 8-15 m.
15-40 m	This option selects moderately deep wells.
> 40 m	This option selects deep tube wells.

6.2.1.12 Energy available

Energy requirement is defined in most of the water methods of the ASTRA tool. Where possible, economic operation may require a cheap, sustainable energy source. This factor helps highlighting these options.

Table 18 **Options and definitions for the screening option 'Energy available'**

Name of category	Explanation in pop-up window
None	Only mechanical or chemical methods, that require only manual operating are selected in this option.
Electricity grid	The availability of an electricity grid supports the implmentation of central treatment methods.
Fuel generated	This option highlights methods that can require fuel.
Solar energy	This option highlights methods that have a proven track record with a solar-powered unit.
Wind energy	This option highlights methods that have a proven track record withwind power.

6.2.1.13 Flood risk

This factor aids the selection of methods depending on their vulnerability to flooding events.

Table 19 Options and definitions for the screening option 'Flood risk'

Name of category	Explanation in pop-up window
Not affected	In general, no flood danger exists in the project area.
Only flooded in extreme weather	Flood may occur, but at a very low frequency. Water method is likely to remain functioning after such an event.
Annually affected by floods	Flooding occurs regularly. Water method needs to be resistant to flooding.

6.2.1.14 Access to site

Especially in rural and remote areas, access to water may take considerable time. This aspect is frequently mentioned as the key reason in low utilization rates of water installations.

Table 20 Options and definitions for the screening option 'Access to site'

Name of category	Explanation in pop-up window
On parcel	This option selects methods normally applied at household level.
Outside of household area	This option selects methods normally available in the vicinity of the household.
<10 minutes to access	This option selects methods that are typically installed at community level in inhabited areas.
<30 minutes to access	This option selects methods that are typically installed at community level in inhabited areas.
>30 minutes to access	This option selects methods that are typically applied outside settlemnts.

6.2.1.15 Construction costs

This screening option indicates the level of required financing for the implementation of the water technology.

Table 21 Options and definitions for the screening option 'Construction costs'

Name of category	Explanation in pop-up window
Negligible	No significant costs are expected for the construction of method.
<USD25	Method constructions that require less than USD25.
USD25-100	Method construction requires USD25-100 per unit.
USD100-1,000	Method construction may require in the range of USD100-1,000.
>USD1,000	Mehtod construction costs are considerable, typically above USD 1,000.

6.2.1.16 Maintenance costs

This screening option indicates the level of required financing duing operation (O&M).

Table 22 Options and definitions for the screening option 'Maintenance costs'

Name of category	Explanation in pop-up window
Negligible	Operation of the selected methods is free of costs or costs are negligible.
Less than USD 5 per month	Operation and maintenance costs are expected, but are not significant.

USD5-100 per month	Considerable operational costs can be expected for the selected methods.
More than USD100 per month	High operational costs or expensive part supply is exoected for the selected methods.

6.2.1.17 Time needed to construct

This factor helps selecting methods based on their estimated construction time.

Table 23 Options and definitions for the screening option 'Time needed to construct'

Name of category	Explanation in pop-up window
Insignificant	Method device or installation is readily available.
A day	Method is relatively easy to construct and requires less than a day per unit.
Several days to a week	Method construction requires days (e.g. a deep tube well).
Weeks	Large-scale method requiring a considerable time and possibly large-scale operations.

6.2.1.18 Level of expertise in O&M

Table 24 Options and definitions for the screening option 'Level of expertise in O&M'

Name of category	Explanation in pop-up window
Household	Easy to operate and maintain by unskilled workers or at household.
Local technician	Operation and maintenance can be assured by skilled local experts.
Local government	Operation and maintenance is optomalliy left with a formal, local authority.
External experts	Sophisticated, complex methods that require specially trained experts, often from outside the community or municipality.

6.2.1.19 User acceptance

User acceptance is one of the crucial factors to dermine economic and resilient operation of a method. This factor helps identifying methods with differing level of requirement for awareness raising and or monitoring activities from the implementing organization(s) or authority.

Table 25 Options and definitions for the screening option 'User acceptance'

Name of category	Explanation in pop-up window
No activity	The methods selected have a track record of a high level of user acceptance.
Limited extension	Very limited awareness raising or similar campaign is required from these methods.
Considerable extension	The methods selected require awareness raising and eventual monitoring.
Expensive campaign	The methods selected need extensive awareness raising and possibly training campaign for resilient operations. Regular monitoring of purification quality is required.

6.3 Technology information sheets

Code*	Name of technological method
SD-01	Deep and intermediate tube well
SD-02	Dug well
SD-03	Shallow and shrouded tube wells
SD-04	Well switching
SD-05	Rainwater harvesting and storage
SD-06	Managed aquifer recharge
CO-01	Piped water supply schemes
TR-01	Chemical oxidation
TR-02	Photo-catalytic oxidation
TR-03	Conventional coagulation and filtration
TR-04	Electrocoagulation
TR-05	Iron- or aluminum-based adsorption
TR-06	Zerovalent iron adsorption
TR-07	Membrane-based removal
TR-08	Bioremediation
TR-09	Phytofiltration
TR-10	Permeable reactive barriers
TR-11	Subsurface arsenic removal
TR-12	Evaporation-based removal
TR-13	Pond Sand Filter
TR-14	UV disinfection
TR-15	Chlorination
TR-16	Boiling
TR-17	Ceramic pot filter
TR-18	Infiltration galleries
TR-19	Riverbank filtration

** SD: Source development; CO: Conveyance; TR:Treatment*

SD-01 Deep and intermediate tube well

Category	Content
DESCRIPTION	A deep tube wells (DTW) aim to abstract water from a deep water layer (aquifer). The depth depends on the geographical and geo-hydrological situation, per definition the water comes from a water layer below an impermeable or confined layer. Drilling the wells might be conducted with manual or machine drilling techniques. After drilling, a PVC tube is placed as casing, with at the lower side a filter. The DTW is mostly equipped with a handpump for abstraction, but it is also possible to use a motorized pump. In the last case it might be extended with a small piped supply network.
APPLICABILITY	Deep tube wells are more high-tech than other well options, since more advanced drilling techniques are required (in some cases stone or rock cutter (Diamond cutter)). The depth of DTWs varies from 100-300m. The DTWs are mainly constructed for communal use. Its main strength is the water quality, both in terms of biological and chemical contaminations. Deeper water layers do mostly not contain arsenic and iron.
REQUIREMENTS	Drilling a DTW requires suitable drilling materials. In sandy grounds (e.g. southern part of Bangladesh) drilling can be conducted with manually drilling techniques. This requires mainly time and human effort (about 10-12 days with 7 laborers), besides some basic materials. In case of harder soils, machine drilling is preferred. These machines might be mounted on a truck or trailer and may be accompanied by large compressors or mud pumps. Maintenance of the tube well itself is minimal. Only the maintenance of the pump requires technical skills.
FINANCIAL	A 300m deep tube well might cost about 500-700 USD, if drilled manually. In case of machine drilled wells, per unit costs might be 1000-1500 USD. O&M costs are estimated to be very minimal, some 1-3 USD per month.
INSTITUTIONAL	The well drilling can best be done by a specialized company or trained local mason group. They are usually hired by the implementation program. For wells that are drilled by machine, it is common to do a geo-physical survey by a geo-hydrologist to determine the site with the best potential, drilling depth, drilling method and expected yield. The management of the well does mainly relate to the pump maintenance. In case of communal use, a management committee might be formed to take the responsibilities.
ENVIRONMENTAL	Deep tube wells feature good quality water and resilient well construction if well specified in contracts. Increasing the number of deep wells in an area may result in the lowering of groundwater level. Design needs to anticipate on low water levels during dry periods. The risk of collapsing is low, deep tube wells can deal with heavy rains.
TECHNICAL	Construction of a deep tube well can be done in several days with manual drilling or in one day with machine drilling. Drilling in sand is often conducted with jetting: water is pumped through a drilling pipe, eroding the soil. Water and cuttings are transported up between the drilling pipe and the borehole wall. This drilling requires less technical skills than machine drilling in harder soils. For the latter one a supervising specialist is required. In case of proper construction, a deep tube well requires minimal maintenance.

SOCIAL	High acceptance level by users due to good quality drinking water. The constructed deep wells offer an ideal public health improving solution in areas where both surface and shallow groundwater is contaminated. However, a water quality test is recommended. Equipment for pumping might include sophisticated technologies that make local maintenance difficult.
BANGLADESHI APPLICATIONS	DTW is a safe water option in many regions in Bangladesh. In 2009, the number of DTWs in Bangladesh was about 162,000. Since then this number has rapidly increased and it is still growing. Many organizations are busy implementing new DTWs: ICCO, Max Foundation, Oxfam, Ashroy, Dalit, DPHE, DORP, DSK, ESDO, Friendship, GUK, GMF, HP, JJS, JICA/AAN, Mukti, NGO Forum, SPACE, UST, Uttaran, VERC and WaterAid.

SD-02 Dug well

Category	Content
DESCRIPTION	A dug well is constructed by excavating a shaft, generally manually and installing a casing where needed. Dug wells are used extensively for domestic water supplies. They are generally not very deep because these cannot readily be sunk far enough below the water table. Most of these are less than 50 feet deep. They generally yield only small supplies of water from water-bearing materials of rather low permeability near the top of the zone of saturation. Dug wells have a typical diameter of 3 to 10 feet. A cover or concrete apron might be made for well protection. A lining can be made of concrete rings or bricks and is applied to overcome collapsing of instable walls. The bottom rings are perforated to allow infiltration.
APPLICABILITY	In coastal areas the tube well is not the only option for safe water source as water table is saline at upper level. Dug wells are constructed in these areas to tap sub surface water. Risk of collapsing in wet season because of the lack of lining or when dug too deep into aquifer. Long dry periods may require deepening of well or an alternative water source.
REQUIREMENTS	A dug well can be used by some 10-25 households. Installation can be done in 3-5 days by about 6 laborers.
FINANCIAL	The costs for a dug well are about 100-200 USD. O&M costs are estimated to be less than 15 USD per year.
INSTITUTIONAL	Dug wells are most often used at household- or shared household-level, but are applicable for small communities. Since little facility management is needed, managing can be easily done by a single person.
ENVIRONMENTAL	Large diameter wells can be made in most soil compositions which provide either clay (containment) or a permeable layer (quick recharge). Digging is best executed towards the end of the dry season when water table is lowest. Design needs to anticipate on low water levels during droughts. High contamination risk, e.g. from latrines.
TECHNICAL	Above the static water table, 3-4 m/day progress can be achieved. Digging becomes difficult below the water table. Dewatering may be necessary to reduce risk of collapsing at this depth. Regular monitoring is advised for contaminations in vicinity of well. Unstable soils or subsoils increase risk of collapsing. Depending on the soil type, cracks might occur in the well lining or platform. This needs to be repaired occasionally. During the dry season the well might be cleaned emptying it, cleaning the walls and disinfection.
SOCIAL	Dug wells are in general highly affordable and locally acceptable. Especially organic (pathogenic) risk to public health from surface, vegetation, and animal excreta. Household-level water treatment is recommended. Cover on well reduces risk of contamination but also the risk of children falling in.
BANGLADESHI APPLICATIONS	The top of shallow aquifers, at less than 10m, appears to be less contaminated than deeper water. This makes the dug well an appropriate alternative water option in arsenic-prone areas. The main problem with the dug well is the hygienic safety of the water. Examples of oganizations who are working with dug wells are DPHE, NGO Forum and WaterAid.

SD-03 Shallow and shrouded tube wells

Category	Content
DESCRIPTION	A shallow tube well (STW) is used to abstract groundwater from shallow aquifers, above the first impermeable layer. After drilling, a PVC tube is placed as casing, with at the lower side a filter. Drilling the wells might be conducted with manual or machine drilling techniques. The STW is mostly equipped with a handpump for abstraction, but it is also possible to use a motorized pump. A shallow shrouded tube well is applicable where the surface as well as deep ground water is saline and there exists no water bearing aquifer. The rainwater accumulated in the subsurface soils at depths 15-20m can be abstracted with such shallow tube wells that are shrouded with coarse sand.
APPLICABILITY	The depth depends on the geographical and geo-hydrological situation. It might be very shallow, starting from a depth of 10 meter. But if the first impermeable layer is very deep, STWs can be even up to 150 meter. The STWs might be used for household level or small community level water supply. It is a cheap water supply option, but in dry period the water level might decline resulting in a lack of water. On top of that, the water from the shallow aquifers might have chemical contaminations.
REQUIREMENTS	Drilling a STW requires suitable drilling materials. In sandy grounds (e.g. southern part of Bangladesh) drilling can be conducted with manually drilling techniques. This requires mainly time and human effort (about 3-5 days with 5 laborers), besides some basic materials. In case of harder soils, the drilling might take longer.. Maintenance of the tube well itself is minimal. Only the maintenance of the pump requires technical skills.
FINANCIAL	A STW might cost about 150-350 USD. O&M costs are estimated to be very minimal, some 7-15 USD per year.
INSTITUTIONAL	The well drilling can best be done by a specialized company. The management of the well does mainly relate to the pump maintenance. STWs are mainly used by only one or a few (10-20) households, making the management relatively simple.
ENVIRONMENTAL	Compared to the subsurface ground layer and the deeper layers, shallow aquifers have more problems with chemical contamination (arsenic, salinity, iron, manganese). In order to avoid water layers with this problems, well drilling can use methods to identify the layers without contamination. Examples of these methods are the Hach kit, needle-sampler and the sediment-color method. Besides the water quality, the design needs to anticipate on low water levels during dry periods. The risk of collapsing is low, deep tube wells can deal with heavy rains.
TECHNICAL	Construction of a shallow tube well can be done in several days with manual drilling or in one day with machine drilling. Drilling in sand is often conducted with jetting: water is pumped through a drilling pipe, eroding the soil. Water and cuttings are transported up between the drilling pipe and the borehole wall. Another common option is sludging in which drill pipes are moving up and down, loosening the soil with the drilling bit. Water and cuttings are moved upwards through the pipe with a hand as valve at the upper side of the pipe. After construction a shallow tube well requires minimal

	maintenance. The main ongoing activies are cleaning the platform and maintaining the pump. After a longer period (very rare) a STW might require a rehabilitation.
SOCIAL	User acceptance of STWs depend on the water quality and water availability. Both these items can be problematic with STWs. But since it is an easy and affordable water supply option, the acceptance is in general good. Consequences of the contamintation are mostly encountered only on the long term. Awareness raising is required for the risk of chemical contamination. Water quality tests are recommended.
BANGLADESHI APPLICATIONS	In 2009, the number of STWs in Bangladesh was about 662,000. A STW is the most common water supply option in most areas of Bangladesh. In coastal areas it is less suitable because of salinity. In other areas there are problems with declination of the water level in the dry period. But the main problem with STWs is the chemical contamination, of which arsenic is the most important one. The arsenic problems make that STWs are not promoted anymore in Bangladesh. Arsenic identification methods during drilling might help to avoid the abstraction of water from arsenic containing layers. Next to that, people might switch to the non-contaminated wells. Examples of organizations working with shallow wells are Dalit, DPHE, Friendship, GUK, JICE/AAN, NGO Forum, SPACE and WaterAid.

SD-04 Well switching

Category	Content
DESCRIPTION	Because of the highly spatial variability of arsenic contamination in Bangladesh, close to 90% of inhabitants live within a 100 m distance of an arsenic-safe well. After arsenic testing, a well can be colored green or red in order to indicate whether it is safe or not. If people switch to a safe well at least for drinking water, the health risks can be significantly reduced.
APPLICABILITY	Well-switching is an arsenic mitigation strategy that is applicable in areas with (1) highly variable arsenic concentrations, (2) frequent monitoring of arsenic concentration in tube wells, and (3) safe environment for users to travel to neighboring wells. From a policy level it can be a very cheap and effective arsenic mitigation option, but its weakness is the dependence on people's personal choices.
REQUIREMENTS	For safe well-switching it is key that solid monitoring of tube wells is practiced throughout the country. Besides the monitoring and coloring, intensive awareness raising is required. Well switching does not require new installations.
FINANCIAL	At least an arsenic test per tube well per year is required (with a cost of approx. USD 1/test), in combination with communication campaign to stimulate behavior change. Although an arsenic test is relatively expensive (approx. 1USD/test) it does not come close to the costs for water treatment.
INSTITUTIONAL	Well switching is a household's choice. It is best to implement this method at a larger scale (e.g. community, village or district) level. Campaigns can be done for a larger group at once and people who switch can be an example for others to make the same choice. Also the organization of the yearly re-testing of wells can best be conducted at the central level.
ENVIRONMENTAL	Highly increased use of safe wells may lead to over-abstraction. The water availability during the dry season might not be sufficient.
TECHNICAL	The technical requirements of well switching are minimal, since there is no need for constructing new infrastructure. The main requirement is the arsenic testing equipment. This equipment needs to be available for the yearly tests.
SOCIAL	User acceptance is an important issue for the well switching option. Instead of using the closest (or own) well, users need to walk further to get water. On top of that, the water might be more expensive than their own water or the water from the closest well. And because of the more intensive use of the safe well, the fetching time is also likely to increase. All these issues make the awareness raising extra important. Visualization of arsenic contamination with a low-cost rapid screening tool can aid in consumer awareness and behavior change.
BANGLADESHI APPLICATIONS	Well-switching was recommended to be more systematically encouraged for Bangladesh in a Bulletin of the World Health Organization in 2002. In 2004, well-switching was recognized as a viable option in the National Policy for Arsenic. Is has been suggested that well switching has been responsible for most of the reduction is arsenic exposure in Bangladesh. But despite the effect, there is a lack of attention for well switching in Bangladesh. More

	focus is given to alternative water supplies, for example deep tube wells.

SD-05 Rainwater harvesting and storage

Category	Content
DESCRIPTION	Rainwater can be collected from the rooftops of houses, schools or other buildings. Roofs with galvanized iron sheets work best for collection, but tiles and sheets are also acceptable. Applicable above 200 mm precipitation per annum, but long dry periods will necessitate an alternative water source. Risk of contamination with suspended solids.
APPLICABILITY	Rainwater is usually harmless and collection requires only simple technology. If collection and storage is done safely, it provides clean water at low costs. If O&M is been done properly, the RWH systems can last for 15-20 years. A main issue is that people are more habituated to other water supply options compared to rainwater harvesting.
REQUIREMENTS	A rainwater harvesting and storage system is most common for household use, mostly 4-5 households per installation. But also community or schools systems are possible. Installation requires about 8-10 days with circa 6 laborers. Maintenance requirements are minimal and can be conducted by one or two persons.
FINANCIAL	Usually, roofs are already in place. If not, investment is needed for adequate roofing. If yes, these costs might be prohibitive for household(s). Additional costs may occur in the form of household treatment or storage/conveyance facility construction. Bangladeshi cost estimates are 200-400 USD per installation or >1000 USD for community based installations. Monthly O&M costs are estimated to be 0.5-3 USD.
INSTITUTIONAL	Optimal decentralized method; can be managed at (shared) household-level. More facilities may prompt establishment of local water committee to optimize managing. Resilience can be improved by organized - professionalized, regional-level - monitoring. Proper (micro-)credit scheme is essential for local dissemination.
ENVIRONMENTAL	Good solution if sufficient rainfall and no other good quality water sources. Often insufficient for year-round consumption. This may require alternative water source development. Water quality might be problematic: roof corroded or contaminated with dust, leaves, insects, bird droppings, etc.
TECHNICAL	Maintenance is simple but requires regular and careful attention. Roof should be frequently cleaned, ideally after every dry period exceeding one month. The initial precipitation is not for storage, but for flush-cleaning system. Before storing rain water, storage reservoir needs to be cleaned with bleaching powder. Manhole Lid of the tank should be removed in absence of sunlight. No branches of trees above the roof catchment. Large-scale roof repairs can be executed by local craftsmen.
SOCIAL	Requires an awareness-raising campaign to acquaint potential users with this solution. Periodically, people might use unimproved sources if water yield is insufficient. Mostly used for drinking and cooking water

	only, because of low yield. In schools often used for hygiene and gardening.
BANGLADESHI APPLICATIONS	Rainwater harvesting and storage is becoming well known and popular in Bangladesh. Campaigns are organized, using mass media both electronic and print: posters, workshops, seminars, dialogue, etc. According to the seasons in Bangladesh, rainwater harvesting is limited from November till March. Especially at the end of this period it might become problematic, if not enough storage is available. Organizations who are working on rainwater harvesting methods are ICCO, Oxfam, Ashroy, BASA, Dalit, DPHE, ESDO, Friendship, GMF, JJS, Mukti, NGO Forum, SPACE, UST, Uttaran, VERC and WaterAid.

SD-06 Managed aquifer recharge

Category	Content
DESCRIPTION	Rain water is collected from roofs and ponds and is infiltrated into the subsurface with infiltration wells. This water can be pumped and used during the dry season. In case of water from ponds, turbidity is first removed using sand filters. The subsurface functions as a large storage facility for the surplus rainwater.
APPLICABILITY	Advantages of subsurface rainwater storage over above-ground storage include the prevention of evaporation and degradation of microbial water quality. Disadvantages of subsurface rainwater water storage are the loss of fresh rainwater through mixing the original groundwater and the uncertainty of dissolution soil-based contaminants (e.g., arsenic). Monitoring of a subsurface system is more challenging than above ground and hydrological and geochemical modeling is often required.
REQUIREMENTS	Managed aquifer recharge (MAR) can be applied at local or centralized level. Infiltration wells with sufficient water collection might be used by 30-40 families during the dry season. Labor is required for design, construction and monitoring. During MAR, the water infiltrates downwards to the recharge aquifers, requiring that there is a sandy, permeable soil.
FINANCIAL	The total costs for the water from such a MAR system constructed by Acacia are about 2 USD/m3, of which about 0.75 USD/m3 is O&M costs and the rest investment costs. This is far cheaper than other available options like rainwater harvesting, water vendors or reverse osmosis. Total investment costs for 30 households excluding source renovation like pond, might be about 900 USD.
INSTITUTIONAL	This method is best applied at a (semi-)centralized level. Several rainwater collection constructions (e.g. roofs) might be linked to a central infiltration well. In case of using pond water for artificial infiltration, there might be issues with the owners of the ponds. The management of the aquifer recharge methods might be conducted by a community committee or a company or local government.
ENVIRONMENTAL	The effectiveness of the aquifer recharge depends on the local soil condition and on the total amount of water that can be injected. In case of water injected in a layer above a saline or brackish layer, there is a risk of water becoming brackish and thus non-drinkable.
TECHNICAL	Managed aquifer is a simple method to store water in the subsoil for later use. Although its simplicity, experts are required for monitoring what is really happening with the water in the subsurface. Also the design of the total system requires expert input. Main items of the installation is the collection point (either roofs or ponds), conveyance system to the infiltration well, the infiltration well itself and the means for abstracting the water from the well again. In filtration wells might be about 15 meter deep and need to allow sufficient infiltration of the water from the well into the soil.
SOCIAL	Managed aquifer recharge might give problems with the taste of the water, caused by the high organic matter content of the ground. Leaving the water for one day before drinking solves this problem. People might not be familiar with managed aquifer methods, resulting in a lower adoption rate.

BANGLADESHI APPLICATIONS	Available groundwater in the western delta of Bangladesh is too salt during the dry season. Even deep groundwater (100-300m) is salt. Above ground storage is insufficient and of poor quality. In this region, south of Khulna and Satkhira, about 20 MAR systems have been built with the help of Acacia (Netherlands). Action research is jointly conducted with Dhaka University, UNICEF and DPHE. Many more systems are planned to be build. Also smaller NGOs are becoming involved, e.g. GMF, JJS, Mukti and Practical Action.

CO-01 Piped water supply schemes

Category	Content
DESCRIPTION	A potential centralized water distribution (and treatment) system. It is a simplified, small-scale version of urban systems. In the system, water is transported from a surface but more often a groundwater source. Primary design at source is a deep tube well. Connection scale may vary from community (public standpost), to shared household, single household and multiple in-house connections.
APPLICABILITY	Two basic scenarios include (i) simple piped scheme containing limited treatment (disinfection step advised) and treatment-containing versions. Former is potentially applicable in arsenic-contaminated areas with a safe aquifer nearby the location of use; latter can optimally function where available safe water alternatives are restricted (potentially in the high salinity areas of South-West Bangladesh).
REQUIREMENTS	Proper financing schemes are required to aid implementation of rural piped systems. Once implemented, good local management is decisive for resilient operation. Cost recovery from water tariffs for adequate O&M are a crucial requirement, but quality of delivery is a prime driver in that effort. BRAC WASH I identified that temporary subsidy to the hardcore poor users may contribute to sustainable operation and feasibility without this subsidy may alter feasibility of this system. Limited delivery of water prompts households to apply additional storage to meet daily need.
FINANCIAL	Costs to implement system can differ a lot, depending on the size of the system it might be between 3,000-200,000 USD. O&M is estimated to be 100-130 USD per month. Users are expected to contribute to 10% capital costs and a monthly tariff in the range of 0.65-2.35 USD, based on level of connection (VERC, 2013) from shared household to multiple in-house connections, respectively. (The ERR (economic rate of return) is reportedly lower than for non-piped solutions BWSPP (2011)).
INSTITUTIONAL	BWSPP (2011) outlined the key steps in the planning phase of rural piped water supply initiatives as (i) request of Expressions of Interest, (ii) pre-screening of respondents, (iii) signing a Memorandum of Understanding, (iv-vi) approving Inception reports, feasibility and design studies and (vii) signing the grant agreement. Total time for this progress is indicated to be ~3 years. Optimal management is often in hands of a local committee or CBO with monitoring executed by NGO staff (VERC, 2013).
ENVIRONMENTAL	No adverse environmental effects were reported for this method. Potential risk of suboptimal arsenic-treatment may occur if aquifer contains other contaminations (iron, manganese) as well. Arsenic-containing sludge removed from the treatment process may present a source of pollution.
TECHNICAL	Feasible size of implementation is from 400 households (BWSPP, 2011) or 2,050 users (VERC, 2013), but reports mention systems with one deep tube well for 10-100 households. Time needed to implement the physical structure is ~90-130 days involving 120 masons and 220 laborers (VERC, 2013).Proper implementation yields an installation with a 20-25 year timespan, if properly

	maintained.
SOCIAL	Very strong user preference is indicated regardless of income level. If properly implemented, such systems can safely deliver contamination-free water. The comfortable (fetching-free) water access is reported to prompt a level of willingness-to-pay that is not characteristic to non-piped systems. Surveyed rural inhabitants are shown to be able to provide the necessary contribution of 10 % (capital costs) for realization of network.
BANGLADESHI APPLICATIONS	For already more than a decade, the BAMWSP concept of cost-sharing prevails in Bangladeshi practice. The large-scale World Bank initiatives of BAMWSP, BWSPP and BWRSSP each included realization of rural (and also pourashava) piped schemes. Challanging implementation prompted local capacity building. At present, DPHE and its daughter institutes, BRAC, RDA and VERC are identified as organizations actively participating in piped water implementations. RDA implemented a number of multiple use systems with irrigation capacity. Other organizations working on piped supply systems are JICA/AAN, UNICEF, UST and WaterAid.

TR-01 Chemical oxidation

Category	Content
DESCRIPTION	Oxidation of As(III) species to As(V) species via simple aeration is slow and inefficient. Chemicals including gaseous chlorine, hypochlorite, ozone, permanganate, hydrogen peroxide, manganese oxides and Fenton's reagent (H2O2/Fe2+) can be employed to accelerate oxidation. Chlorine is a rapid and effective oxidant, but it may react with organic matter, producing toxic and carcinogenic trihalomethanes and other disinfection by-products. Potassium permanganate effectively oxidizes arsenite, and it may be a widely available inexpensive reagent suitable for developing countries. Hydrogen peroxide can also be an effective oxidant if the raw water contains dissolved iron, which often occurs in conjunction with arsenic contamination, allowing the occurrence of Fenton reactions.
APPLICABILITY	Chemical oxidation can be applied at local or centralized level. However, at household or small community level the storage and handling of concentrated chemical reagents always represents some risk. Chemical oxidation can give a main improvement for the further removal of arsenic from the water.
REQUIREMENTS	Main requirements are the chemicals. Only the basic options like chlorine or potassium permanganate might be available. Proper construction of the dosing system is required, expert input is needed.
FINANCIAL	Potassium permanganate is more expensive than chlorine (e.g. seven times cheaper) but has lower risks in delivering clean water. Costs for centralized chemical oxidation will be part of the total cost for a centralized treatment plant. Capital investment costs for the oxidation unit might be 7,000 USD or higher.
INSTITUTIONAL	Chemical oxidation is best implemented in combination with a centralized follow-up treatment. Management might be conducted by a water company or government might take responsibilities. In case of smaller applications, community management might be suitable.
ENVIRONMENTAL	When using chlorine as an oxidant, by-products require additional treatment. These by-products are harmfull to people and cannot be disposed untreated.
TECHNICAL	For the addition of the chemicals a proper feed and dosage system is required including storage facilities for the chemicals. Maintenance requirements are minimal, approximately one hour per week in case of centralized treatment. Other removal steps are required to remove the arsenic (coagulation/flocculation/filtration).
SOCIAL	Chemical oxidation is mainly applied at a centralized level and does not require specific actions from the water users. The main effect for the users is that the quality of their water is more likely to be safe. Safer water is expected to go together with an increased willingness to pay for the water.
BANGLADESHI APPLICATIONS	In Bangladesh, this pre-treatment has been widely applied at both household and community level.

TR-02 Photo-catalytic oxidation

Category	Content
DESCRIPTION	The process of As(III) oxidation can be accelerated under UV light irradiation in the presence of oxygen. Addition of H2O2 to the UV system triggers As(III) oxidation through H2O2 photolysis, which generates HO● radicals, powerful oxidants. Based on these concepts, the SORAS (solar oxidation and removal of arsenic) method was developed as a very simple process designed to provide As-free drinking water to population of very low levels of income. The raw water is filled in transparent PET bottles and exposed to sunlight for several hours. Citrate, added to the raw water in form of lemon juice, reacts with Fe(III) present in the natural raw water or added from an external source. The photo-catalytic methods using TiO2 as photo-catalyst, followed by iron addition, is another recently developed, low-cost technology, suitable for As removal from water.
APPLICABILITY	Depending on the specific application, solar oxidation can be either applied at household level or at a more centralized level. Especially the SORAS option is a low-tech method. When using the sunlight, it is a cheap method. If combined with precipitation or filtration, an average As removal efficiency of 67% can be achieved.
REQUIREMENTS	The main requirements for the SORAS method are pet bottles, sunlight and citrate. These are common available products. Installation requirements are minimal. In case of using a more advanced photo-catalyst, installation requirements are more and experts are needed for the operation.
FINANCIAL	Financial aspects depend on the specific application, but in most cases the installation costs are low. Operation costs are low when only using sunlight and simple citrate. Using photo-catalysts like H2O2 or TiO2 is more costly and goes together with higher staff costs.
INSTITUTIONAL	Simple applications of solar oxidation can best be applied at the household level. Advanced application with a photo-catalyst are more suitable for centralized water treatment. Local authorities can play a significant role in dissemination of the solar oxidation option.
ENVIRONMENTAL	This method has very little environmental impact, especially when using the SORAS application. In case of adding H202 or TiO2, the byproducts need careful handling. Disposal of these materials in settlement areas can contaminate soils or water sources, posing a public health risk to the population.
TECHNICAL	Household level application of solar oxidation can only treat a limited amount of water per time and it takes several hours. Addition of an advanced photo-catalyst accelerates the process, but this option is more expensive and more complicated. Main recurrent item is the citrate or other catalyst.
SOCIAL	In case of centralized treatment, the required actions for the water users are negligible. For household level solar oxidation, the users need to conduct several actions, including filling of bottles and adding citrate. There is a serious risk of not conducting the actions in the right way (e.g. adding a wrong amount of citrate). On top of that, the oxidation process might not always work optimal, resulting in remaining dangerous arsenic levels in the

	water.
BANGLADESHI APPLICATIONS	SORAS has been adopted with partial success to remove arsenic from groundwater for individual consumption in Bangladesh.

TR-03 Conventional coagulation, filtration

Category	Content
DESCRIPTION	Arsenic removal by coagulation and filtration has been successfully applied for decades and constituted a solution for the problem of arsenic for both communities and small cities. The coagulation-filtration technology is simple, only common chemicals are used, installation costs are small and it can be easily applied to large water volumes. Arsenic is removed in the pentavalent form, which adsorbs onto coagulated flocks and can be then removed by filtration. As(III) has to be previously oxidized. The most used coagulants are aluminum sulfate (Al2(SO4)3), iron chloride (FeCl3) and ferrous sulfate (FeSO4), iron salts being generally better removal agents and efficient on a wider pH range.
APPLICABILITY	Coagulation is known to be a very effective treatment method for most contaminations, but it removes arsenic only moderately. The method requires continued supply of coagulants and produces toxic sludges that need to be treated or safely landfilled.
REQUIREMENTS	The requirements for coagulation depend on the scale of use. Coagulation might be applied even at household level, requiring minimal input. In case of coagulation and flocculation in community based treatment, it requires skilled people to take care of the process.
FINANCIAL	An efficient treatment method, but the coagulant requirement makes it relatively expensive. An arsenic and iron removal plant for 25 households might cost about 500 USD.
INSTITUTIONAL	Can be applied at local level or centralized level. Typical application as part of a treatment-train, followed by sedimentation or filtration. Skilled people are required for proper application of coagulation chemicals and proper mixing.
ENVIRONMENTAL	Highly contaminated flocks removed in next treatment step. In case of sedimentation it will be clogged into sludge, in case of granular filtration the flocks will end up in backwash water. Aluminum-containing sludge presents high risk for surrounding groundwater contamination.
TECHNICAL	Coagulants are stored and added to water in solution form. Optimal dosing depends on composition/contamination of water, which requires adequate testing equipment/laboratory. Mixing can be conducted mechanically or hydraulically. Maintenance is minimal compared to operational requirements. Effluent monitoring required.
SOCIAL	Coagulation/flocculation is typically part of a larger treatment installation. No specific concern for users, therefore no special awareness-raising required. Treatment workers need to be aware of health risks of coagulants and sludge, they need protecting gear when handling these materials.
BANGLADESHI APPLICATIONS	Earlier this method was widely used for surface water treatment, especially in the rural community due to the absence of tube wells. Now its use is gradually decreasing and during emergency, a certain percentage of affected people normally uses this technology. For arsenic removal this method is known in Bangladesh, including household level applications (e.g. the Bucket Treatment Unit). Comparable to this method, Bangladesh has a lot of experience with removing arsenic in iron removal plants, with mainly aeration and filtration (AIRP). Arsenic is attached to the formed iron hydroxide flocs. Examples of organizations who are working with AIRPs are Oxfam, Ashroy, BASA, GUK, HP, JICA/AAN, Mukti, SPACE, UST and WaterAid.

TR-04 Electrocoagulation

Category	Content
DESCRIPTION	Electrocoagulation uses electricity with metal plates/electrodes instead of chemicals. Electrocoagulation for arsenic has been achieved by iron and aluminum, with iron representing the most efficient choice (Ali et al. (2011)). The electrocoagulation process can be divided into three parts: (i) electrolytic oxidation of the sacrificial anode and, thus, formation of coagulants, (ii) The rust forms complexes with arsenic in solution through adsorption to the rust surface, or precipitation into a new iron-arsenic solid and (iii) aggregation of the destabilized particles to form flocs. Subsequently, sedimentation of the flocs is slow, but it can be accelerated by dosing 2 mg/l of Al^{3+} (Li et al. (2014)). Alternatively, flocs can be removed by filtration using a sand filter or microfiltration membranes. Arsenic-removal efficiencies are generally above 90%, and optimization can lead to a reduction of As concentration from 100-500 µg/L to less than 10 µg/L.
APPLICABILITY	Although arsenic removal with electrocoagulation is still a new development, it has a high potential for use in Bangladesh. It uses relatively simple materials and no chemicals need to be added to the water. The coagulation and flocculation process is also likely to be better and faster than with the conventional chemical coagulation. The contaminated sludge is easier to treat since flocs are larger, contain less bound water and are more stable.
REQUIREMENTS	Electrocoagulation requires metal electrodes (mostly iron) with electricity connection. Installation is relatively easy and can be done in a few hours. Skilled persons are required for the operation and maintenance of the method.
FINANCIAL	Arsenic removal with electrocoagulation is still new but it is expected that money can be saved with using electrocoagulation instead of the conventional chemical coagulation. Less chemical are required and the contaminated sludge is easier to treat.
INSTITUTIONAL	Electrocoagualtion can best be applied within a central treatment plant. From there water can be supplied to a large group of people, e.g. with a piped supply network. Management of the treatment might be conducted by a water company or government might take responsibilities. In case of smaller applications, community management might be suitable. Because of less experience in Bangladesh, involvement of experts is required for the implementation.
ENVIRONMENTAL	Electrocoagulation goes together with contaminated sludge, but this sludge is easier to treat compared to sludge from conventional coagulation and precipitation processes. The sludge might be dewatered and needs to be disposed at a safe location, for example it might be stabilized in concrete.
TECHNICAL	Electrocoagulation can be applied with a simple process setup. Maintenance requirements are less than for the conventional coagulation since there are less moving parts (e.g. no stirring equipment and no dosing mechanisms). Electrodes are slowly getting less and need to be replaced after a long period.
SOCIAL	Adsorption is mainly applied at a centralized level and does not require specific actions from the water users. The main effect for the users is that the quality of their water is more likely to be safe. Safer water is expected to go

	together with an increased willingness to pay for the water.
BANGLADESHI APPLICATIONS	Electrocoagulation has not been widely applied in Bangladesh. But field tests are conducted and show good results (Amrose et al, 2013). It was found to be highly effective, robust, requiring little maintenance, and producing only small quantities of sludge.

TR-05 Iron or aluminium oxide based adsorption

Category	Content
DESCRIPTION	Adsorption involves the use of granular adsorptive media for the selective removal of arsenic from water with or without pH adjustment and with or without spent media regeneration. A vast variety of materials has been used as adsorbents in arsenic removal (Mohan and Pittman Jr (2007)), but the most conventional technologies adopt aluminum oxides and iron oxides. Iron oxides, oxyhydroxides and hydroxides, including amorphous hydrous ferric oxide (FeO-OH), goethite (α-FeO-OH) and hematite (α-Fe_2O_3), has been always considered good adsorbents for removing both As(III) and As(V) from water (i.e., Ferguson and Gavis (1972); Roberts et al. (2004)). Amorphous Fe(O)OH has the highest adsorption capability since it has the highest surface area. Arsenic adsorption on activated alumina (AA) has received substantial attention. Activated alumina, prepared by thermal dehydration of aluminum hydroxide, has a high surface area and a distribution of both macro- and micropores. Within a pH range of 5-7, the adsorbent has been successfully applied reaching efficiencies higher than 95% (Pirnie (2000)). Activated alumina can be regenerated,more than 85% of the adsorbed arsenic desorbed in less than 1 h using 0.05M NaOH.
APPLICABILITY	The adsorption technology is simple, does not require chemical addition, and it can be applied at both community and household levels. High arsenic removal levels can be reached with these adsorption methods, although the sorptive media need to be regenerated or replaced in time.
REQUIREMENTS	Main requirement for these adsorption methods is the adsorptive media itself. This is mostly used in granular form. Labor requirements are mainly related to media regeneration or replacement.
FINANCIAL	Granulated ferric hydroxide/oxide is a relatively affordable adsorption method, especially when used at a centralized level. Activated alumina is two to three times more expensive. Material costs are the media itself, chemicals for regeneration, labor and energy costs. A household based Alcan filter is about 65 USD.
INSTITUTIONAL	Adsorption can be applied both at household and at centralized level. Household level applications are less advisable because of the requirements from the users and the risks of improper handling. Adsorption can best be implemented within centralized treatment plants. Management might be conducted by a water company or government might take responsibilities.
ENVIRONMENTAL	During regeneration of the media, chemically contaminated water and grains are produced requiring safe disposal. The toxic solids might be disposed in landfills.
TECHNICAL	Adsorption is a simple method. Water flows through a bed with adsorptive media (mostly grains) and arsenic is adsorbed to the surface of the media. Proper monitoring is required in order to regenerate or replace the media before it is saturated. Adjustment of pH might be required as an additional step.
SOCIAL	Adsorption is mainly applied at a centralized level and does not require specific actions from the water users. The main effect for the users is that the quality of their water is more likely to be safe. Safer water is expected to go together

	with an increased willingness to pay for the water.
BANGLADESHI APPLICATIONS	Both iron- and aluminum-based adsorption methods are well known in Bangladesh. Examples of household level applications include Alcan and Shapla. For use at household level many alternative arsenic adsorbents are in use (e.g. iron rich soils, clay minerals and other iron fillings). Research on adsorption method is (amongst others) conducted by BUET University.

TR-06 Zerovalent iron adsorption

Category	Content
DESCRIPTION	Zerovalent (solid) iron particles are widely available. Any local iron materials, iron wool, packing wire or scrap from planing machines can be used. ZVIs in combination with air and water will corrode to Fe(II) and Fe(III) (hydr)oxides. Arsenic can adsorp to these iron hydroxides. A household based example with ZVI is the SONO filter. The intermediates formed during the ZVI corrosion can oxidize both As(III) and As(V), eliminating the need for pre-oxidation. But removing of As(V) is faster than removal of As(III).
APPLICABILITY	Zerovalent iron adsorption (ZVI) has several advantages compared to other adsorbents. First of all, it is cheap and widely available in many forms. In addition, the intermediates formed during ZVI corrosion can oxidize As(III) to As(V), which eliminates the need of an additional oxidation, while iron corrosion produces ferric oxyhydroxides (FHO), which strongly sorb As and functions as a continuous regeneration of the filtrating media. ZVI filtration does also remove pathogens from the water.
REQUIREMENTS	Proper aeration of the water is required for this treatment process to be effective, subsequent filtration is advisable. No additional chemicals. The iron particles regenerate themselves, there is a continued oxidizing process. After some 3-5 years, the iron particles need to be replaced.
FINANCIAL	Using zerovalent iron for arsenic removal is a cost-efficient option. A household Sono filter might cost 40-50 USD. No extra costs for chemicals do apply. Maintenance costs are very low. Refilling with iron particles needs to be done after some years, but these costs are limited.
INSTITUTIONAL	Arsenic removal with ZVI can be both applied at the household level or at a centralized level. Management does not require expert skills and might be conducted by households or communities. If applied in a centralized treatment plant, the management will be conducted by the water company or leading institution.
ENVIRONMENTAL	Since the arsenic is adsorpted onto the iron rust, it is possible to safely dispose or reuse the waste. Because of the low requirements in terms of energy and chemicals, this method has a low ecological footprint.
TECHNICAL	The adsoption of zerovalent iron filings for arsenic remediation is dramatically affected by oxygen content and pH. High dissolved oxygen content and low solution pH increase the iron corrosion rate. This makes it important to include an aeration step before the ZVI filtration. Water quality checks are required in order to know whether replacement of the ZVI is needed.
SOCIAL	In case of household level application, users need to put the water in the filter and wait until it is ready. In case of centralized level application it does not require specific actions from the water users. The main effect for the users is that the quality of their water is more likely to be safe, including the bacteriological quality. Safer water is expected to go together with an increased willingness to pay for the water.
BANGLADESHI APPLICATIONS	ZVI is an established technology for water treatment in Bangladesh, both at household and community level. The best known option is the Sono filter. More tests might be required in order to improve the ZVI filtration process.

	Organizations working with ZVI options are Eawag, UST, VERC and Manob Sakti Unnayan Kendro (MSUK).

TR-07 NF and low-pressure reverse osmosis

Category	Content
DESCRIPTION	High-pressure membrane filtration like nanofiltration (NF) and reverse osmosis (RO) is effective in removing both As(III) and As(V) species. However, efficiency in removing As(V) was higher than for As(III) and oxidation is not an easy way to improve the efficiency since oxidant could damage the membrane. Reverse osmosis is also suitable for salt removal. Water with salt is pressed through a semi-permeable membrane under high pressure, leaving the salts behind the membrane. In order to avoid excessive fouling of the membranes, pre-treatment is required. Under current developments the method is becoming more affordable. Also other options are developed, e.g. bicycle pump operated, with lower energy requirements.
APPLICABILITY	High-pressure membrane filtration can be of high value especially in areas with salty or brackish water. It can produce very clean and safe water. But some disadvantages are low water recovery rates (10-20% in case of single membrane module), high electrical consumption, high investment cost, concentrated brine production, and risk of fouling. The use of alternative and locally available sources of energy combined with systems for energy recovery can significantly increase the range of water resources a community can use. The use of an energy recovery system is able to lower the energy consumption by 80%, taking advantage of stored energy in the high-pressure reject water that is typically wasted in conventional systems.
REQUIREMENTS	High pressure membrane filtration requires advanced materials. The membranes are expensive and in most cases need to be imported. High energy input is required for operation, making method less relevant for areas with an unrealiable power network. For cleaning anti-scalant chemicals might be required. Because of the advanced technology and the risks of fouling, expert input is required for operation the process.
FINANCIAL	For arsenic removal more affordable options might be preferred. For removal of salts, membrane-based options might be affordable. But still, investment costs are high and also the running energy costs are high. Alternative solutions with lower pressure use or manual energy input make the membrane option more easy to apply.
INSTITUTIONAL	Can be applied at local or centralized level, but might be too expensive for use at local level. Labor requirements are not much but need education and careful attention, therefore experienced operator is required. This person can operate other (pre-treatment) processes at the same time.
ENVIRONMENTAL	The energy requirements give membrane filtration a high ecological footprint. Produced sludge (concentrate) is highly contaminated, requiring safe handling and disposal to avoid risk to public health and contamination of groundwater.
TECHNICAL	Membrane filtration is a high-tech option. Depending on the specific configuration and contaminant concentrations, the water recovery rate might be relatively low. Operation and maintenance requirements for membranes are minimal, since no chemicals are needed and maintenance consists of only ensuring a reasonably constant pressure and a periodical cleaning of the membrane system. Pre-treatment is required in order to avoid clogging and rapid fouling of the membranes.

SOCIAL	Produces good quality water with high level of reliability if well maintained. Eventual defects are difficult to mend. Water supply might be out of use for long periods, negatively influencing the users' willingness to pay for the centralized water supply. If applied within a central treatment plant there are no further user requirements for the membrane treatment.
BANGLADESHI APPLICATIONS	The common high pressure membranes are not regularly applied in Bangladesh. The main threshold is its high energy consumption. NF and RO is common in several western countries but not in most developing countries. Friendship is working with RO water treatment in Khulna and Satkhira.

TR-08 Bioremediation

Category	Content
DESCRIPTION	Several microbial-assisted arsenic removal technologies have been attempted both in laboratory and field scale. Removal of arsenic from groundwater in a bioreactor occurs by iron-oxidizing bacteria *Gallionella ferruginea* and *Leptothrix ochracea* (Katsoyiannis et al., 2004). Such bacteria oxidizes Fe(II) present in the groundwater which is subsequently precipitated as iron oxides in the filter medium (polystyrene beads). As iron oxides are efficient adsorbents of arsenic, both As(III) and As(V) are possible to be removed from contaminated groundwater with arsenic concentration 50–200 µg/L. As(III)-oxidation was also found to be catalyzed by those iron-oxidizing bacteria, leading to enhanced overall arsenic removal.
APPLICABILITY	Possibly applicable for conventional and small-scale piped water supply systems for rural or low-income urban areas. As a biological treatment step, it requires pre-treatment of contaminations that may affect growth of microorganisms. Because of its relative simplicity and lack of additives, it is expected to be applicable throughout Bangladdesh.
REQUIREMENTS	This method requires extensive R&D before being applied. The operation and maintenance requires specific education for proper managing.
FINANCIAL	No financial considerations are known for this method.
INSTITUTIONAL	As a treatment unit, it can be managed on-site together with other purification units of a waste plant. Operation and maintenance does require trained experts as this treatment is susceptible to alterations in pH and possibly other water parameters.
ENVIRONMENTAL	Microbial growth indicates that surplus sludge may be necessary to treat.
TECHNICAL	No specific design considerations are known, but the upflow-type setup used makes biological wastewater knowledge applicable for biological arsenic removal.
SOCIAL	As a larger treatment unit, it is not in directly utilized by end users.
BANGLADESHI APPLICATIONS	No known applications in Bangladesh so far. In India one long-term operational pilot plant is known, htat can possibly be used as blueprint.

TR-09 Phytofiltration

Category	Content
DESCRIPTION	The potential of using recently identified arsenic-hyperaccumulating ferns to remove arsenic from drinking water was investigated by Huang et al. (2004). Such ferns were able to rapidly remove arsenic from water to achieve arsenic levels below the new drinking water limit of 10 µg/L (>98% removal in 24h). The significantly higher efficiency of arsenic phytofiltration by arsenic-hyperaccumulating fern species is associated with their ability to rapidly translocate absorbed arsenic from the roots into its fronds (Ma et al. (2001)).
APPLICABILITY	Especially suitable in areas where sufficient space is available for treatment unit: outside municipalities or rural areas.
REQUIREMENTS	R&D is required to make this method usable in practice.
FINANCIAL	No information was available until the completing of the ASTRA tool development (2014).
INSTITUTIONAL	If part of water treatment plant, no additional institutional capacity is required.
ENVIRONMENTAL	Accumulated arsenic in plant tissue implies that removed plants should be treated anmd/or landfilled in order to reduce risk of arsenic contamination from degraded plants.
TECHNICAL	No information was available until the completing of the ASTRA tool development (2014).
SOCIAL	As a central treatment method, no direct contact exists withteh end users.
BANGLADESHI APPLICATIONS	No active installations are known for Bangladesh.

TR-10 Permeable reactive barriers

Category	Content
DESCRIPTION	The use of permeable reactive barriers (PRB) and reactive zones is considered as one of the most efficient technologies for in-situ removal of As. In PRB technology, a reactive medium is interposed in the way of the contaminant plume in the subsurface. The appropriate reactive material is able to induce physicochemical and/or biological processes to remediate groundwater contamination. Fe (or Al) oxide-containing materials can be used as relatively cheap passive reactive barriers (Bhattacharya et al. (2002); Gavaskar (1999) ; Gu et al. (1999)). The involved main processes are sorption, precipitation, chemical reaction and/or biogenic reactions (Di Molfetta and Sethi (2012)). The technology has been directed recently to the use of zerovalent iron, as a new sorption medium to remove both arsenate and arsenite. Gibert et al. and Su and Puls achieved values below 10 µg/L in their studies (Gibert et al. (2003);Su and Puls (2003); Su and Puls (2001)).
APPLICABILITY	In order to improve the cost efficiency of the application, PRBs are best applied at a water sources for a large group of people. Treatment of the water occurs in situ and there is no flow of hazardous waste, like from conventional treatment processes. An extra advantage is that there is no ongoing energy input required. More research and monitoring is required in order to compare the advantages with the potential negative impacts, e.g. in terms of aquifer contamination.
REQUIREMENTS	Experts are required in order to make a proper design for the PRB in terms of location, used materials and proper construction. Main labor requirement is related to excavation for placement of the barrier. Expecially in case of deep aquifers, this is a main limitation for the method. Once installed, there is hardly any activity required for operation and maintenance apart from monitoring the process.
FINANCIAL	The construction of a proper subsurface PRB is currently an expensive option. If more experience is gained, more affordable ways of implementing PRBs might be developed. The running costs for the PRB after installation are very low.
INSTITUTIONAL	Because this technology is new and needs extensive monitoring, it is not suitable for local household or community management. An expert company or government unit needs to take responsibilities. Under this responsibility, the method might be used for boreholes with medium or larger user groups.
ENVIRONMENTAL	In first instance, PRBs have less impact on the environment compared to conventional treatment processes because of the lower amount of waste sludges. Also the absence of energy requirements contributes to a low ecological footprint for the PRBs. But more monitoring is required in order to evaluate the long term impacts of PRBs on the aquifer and soil quality.
TECHNICAL	Subsurface PRB for arsenic remediation is a new development. Both technical and economical research is going on. Several materials can be used for the barriers, most of them are based on iron (oxides) of mixes with iron. Implementation requires geohydrological analysis, material selection and excavation and placement activities.
SOCIAL	PRB are not well-known and awareness raising might be required in order to create acceptance of the technology. Since the method is used at a central or

	borehole level, there are no additional requirements from the users after installation. The main effect for the users is that the quality of their water is more likely to be safe. Safer water is expected to go together with an increased willingness to pay for the water.
BANGLADESHI APPLICATIONS	No practical applications of subsurface PRBs were found in Bangladesh. Experiences in other countries (e.g. US and UK) are promising and make it a serious option to consider. But main dissemination activities are required for introduction of PRB applications in Bangladesh.

TR-11 Subsurface arsenic removal

Category	Content
DESCRIPTION	Subsurface arsenic removal (SAR) for the retention of high arsenic concentrations from groundwater is a new approach with great potential for both iron and arsenic removal. The principle of subsurface arsenic removal is that aerated water is periodically injected into an anoxic aquifer through a tube well partially displacing the iron-containing groundwater. The injected oxygen-rich water oxidizes adsorbed ferrous iron on the soil grains, resulting in a surface area of ferric iron hydroxides suitable for adsorption and co-precipitation of soluble ferrous iron and trace elements such as arsenic. When the flow is reversed, soluble ferrous iron in the abstracted groundwater is adsorbed onto the ferric iron coated soil grains and water with reduced iron concentrations is abstracted.
APPLICABILITY	Operation of the subsurface arsenic removal method is simple and does not require specialized personnel. This could make the method applicable for use at local household or community level, but some other factors may limit this application. The method is not effective in all geological conditions, requiring expert analysis before use.
REQUIREMENTS	Subsurface arsenic removal requires a groundwater pump and an aeration and storage facility. Experts are required to conduct proper suitability analysis before construction is started. The installation itself is simple and only requires a few laborers. Some expertise is required for the operation in order to understand when injection needs to be started in order to avoid excessive arsenic contamination levels in the water.
FINANCIAL	Subsurface arsenic removal is found to be cheaper than most other arsenic removal technologies. But the efficiency is highly dependent on the local geochemical conditions. The required pre-analysis of these conditions might create a significant extra financial burden for the use of this method. Maintenance costs for the SAR after installation are very low.
INSTITUTIONAL	SAR is a new technology and any implementation needs extensive monitoring. A lack of geological knowledge at the local household or community level may be a main limitation for use of SAR at this local level. An expert company or government unit needs to take responsibilities. Under this responsibility, the method might also be used for water supplies for small groups of people.
ENVIRONMENTAL	In first instance, SAR has less impact on the environment compared to conventional treatment processes because of the lower amount of waste sludges. Also the low energy requirements contributes to a low ecological footprint for SAR. But more monitoring is required in order to evaluate the long term impacts of SAR on the aquifer and soil quality.
TECHNICAL	Subsurface arsenic removal is a new development. The same method shows great potential for iron removal, but its efficiency is limited for arsenic removal. Under specific conditions, especially with a low a amount of competing contaminant like phosphate, it might work well. Since installation and maintenance is simple and cheap it is still worth to conduct further technical research on the possibilities of using SAR.
SOCIAL	SAR is not well-known. Awareness raising might be required in order to create acceptance of the technology. The limited efficiency in most contexts increases

	risk of unsafe water promting the regular checking of water quality. In case of improper management there is a serious risk of waiting too long before injecting is started again.
BANGLADESHI APPLICATIONS	Subsurface arsenic removal has been tested at several locations in Bangladesh but it is not yet widely applied. More research and evidence is required before widespread implementation.

TR-12 Evaporation technologies

Category	Content
DESCRIPTION	Impure water is inserted into a sealed container where it is evaporated by the sun heat through diverse methods. Although most methods use transparent plastic/glass for the heating up of the contaminated water, there are innovative designs that operate with more complex designs (e.g. the FCUBED). In contact with the plastic/glass surface, the water vapour condenses, and pure water drips down the cover and is collected and removed (Vinoth Kumar and Kasturi Bai (2008)).
APPLICABILITY	Solar thermal distillation is ideal for low capacity and self-reliance water supplying systems since they can produce drinking water based on solar energy only, with no extra energy input.
REQUIREMENTS	Evaporation methods do require a considerable amount of sunshine to operate efficiently enough to fulfill the daily need of one family, but they usually do not require extensive training for use and maintenance.
FINANCIAL	No information was available until the completing of the ASTRA tool development (2014).
INSTITUTIONAL	Efficient dissemination of commercial distillation devices requires a considerable management capacity.
ENVIRONMENTAL	As most devices are small(household)-level, no significant contamination is expected.
TECHNICAL	No specific considerations are available. Specific commercial devices may require (limited) operation and maintenance methods. The maximum efficiency for a conventional solar still is around 50% as compared to full insulation, although typical efficiencies can be 25% and production of drinking water remains between 4-8 L/m2 (CAWST, 2011).
SOCIAL	As the treatments require little activity from the end user, it is likely to have a higher user acceptance than conventional HWTS methods (bucket filtration methods). Cost of household-level distillation unit may require active donor role in efficient distribution.
BANGLADESHI APPLICATIONS	Over 2000 installations of the F CUBED solar distillation devices are indicated to be active in the coastal region of Bangladesh (e.g. via the organization UST). Considering the limited options to efficiently treat saline water with low-tech options, small-scale solar distillation units may prove to be the appropriate approach for low-income families to obtain safe water without extensive household-level management of filtration methods. Another initiative are some field trials with Tubular Solar Stills (e.g. with Aosed Khulna).

TR-13 Pond Sand filter

Category	Content
DESCRIPTION	A sand filter is a common method to reduce the turbidity of surface water and to remove pathogens. Water flows through a sand filter bed and suspended solids (e.g. sand, clay and flocs) are retained. With rapid sand filtration (sand with grain size of 0.4-2 mm diameter) the main removal is by physical processes. With slow sand filtration (fine sand with grain size of less than 0.5 mm diameter) additional biological and chemical processes play a role. The filtrate is collected via nozzles at the filter floor. The key proponent for slow sand filters is the Pond Sand Filter (PSF). In this method, especially surface water is purified from fresh water ponds that are primarily collecting rainwater.
APPLICABILITY	Settling is a simple process that can be conducted both at household and at community level. PSFs are applied at community-level. They are relatively easy to construct and maintain and organisations exist in Bangladesh that can support professional design. Neglecting the maintenance (scraping and replacement of the upper filtration layer), a negative effect on both yield and treatment quality. The limited discharge of a PSF is a problem in case of use at community level.
REQUIREMENTS	Pre-treatment in the form of screening or sedimentation is required. In case of very turbid waters, roughing filter may be added as a pre-treatment option to a SF. Using slow sand filtration is an efficient option to remove pathogens, but it may still benefit from an additional disinfection step at the household (e.g. chlorination or ceramic pot filter).
FINANCIAL	Both construction costs and O&M costs are low. Depending on the size of the unit, Specific Bangladeshi PSFs might cost around 1000 USD for an installation for about 100 households or 150 USD for 15 households. O&M costs are low.
INSTITUTIONAL	PSFs are optimally managed by local committees that monitor water quality and ensure regular filter cleaning. In Bangladesh, DPHE and WaterAid Bangladesh can offer technical assistance for the local implementation of this method. No significant institutional labor is required for the management.
ENVIRONMENTAL	PSF use depends primarily on the availability of pond water. In many cases, this water is only available in parts of the year. Only 36% of the operating PSFs were reported to produce water throughout the whole year. Removed sand and sludge needs safe disposal. If put in waste pit, leaching contaminants might affect water source and pose a health risk.
TECHNICAL	Simple to construct, mostly using masonry or concrete. Design inlet arrangement must ensure the even and turbulence-free supply of water in tank to keep settling efficiency high. Depending on the turbidity of the source water, cleaning frequency of PSF is indicated to be between 1.5-5 months. Cleaning (the scraping of the top layer (1-3cm) of filter) can be

	done in 45 minutes with two workers. If a roughing filter is added, the cleaning frequency can be lowered (Ahmed et al., 2002). Regular removal of sludge required. Washing the filter beds is sometimes found to be difficult and not always done properly. Installation maintenance is minimal. Effluent monitoring required.
SOCIAL	Dependance of the PSF on proper ponds may prompt considerable walking distances for the primarily female users (0.5-1.5 miles) (UNEP-IETC, 2014a). Fish cultivation is a conflicting activity in the source water with the application of a PSF. The preservation of the quality of the source pond is a crucial issue and needs to be managemd together with the user community. If the raw water is too contaminated, additional (household-level) treatment may be necessary. Since the method is simple and commonly known, the expected acceptance level is high.
BANGLADESHI APPLICATIONS	In 2009, the number of pond sand filters in Bangladesh was about 5,800. It is less common than tube wells and it is mainly used in areas where access to groundwater is not sufficient. Especially applied in the coastal regions of Bangladesh, in saline- and drought-prone areas, by organizations like ICCO, Oxfam, Ashroy, Dalit, JICA/AAN, JJS, Mukti, NGO Forum, UST, Uttaran and WaterAid.

TR- 14 UV disinfection

Category	Content
DESCRIPTION	A disinfection method that applies ultraviolet (UV) radiation for the destruction of microbiological DNA. Designs involve either mercury-filled UV lamps placed next to the water flow or water bottles which are exposed to the sunlight. The treatment efficiently removes bacteria, protozoa and most viruses primarily from surface water sources.
APPLICABILITY	UV treatment is an effective disinfection method. Although it does not deal with recontamination of the water.
REQUIREMENTS	Requirements depend on the specific application. In case of SODIS, the requirements are minimal. UV lamps are more expensive and need electricity.
FINANCIAL	Considerably higher costs than chlorination, but still a relatively inexpensive method. Costs involve material and electric power expenses. Lifespan most lamps: 6,000-10,000 working hours.
INSTITUTIONAL	Mostly used in central water treatment. Can be managed by unskilled personnel. UV treatment is used in combination with other processes (for removal of turbidity and chemical contaminants). Minimal managing requirements allowing execution jointly with other treatment plant activities.
ENVIRONMENTAL	Environment related issues are estimated to be minimal. Only mercury lamps itself might represent serious health hazard when not properly disposed. The efficiency of UV treatment might be reduced in case of increased water flow (like with heavy rainfall events) because of high turbidity water.
TECHNICAL	Simple and efficient process. Sufficient UV-C (100-280 nm) radiation required. No chemicals involved. Easy in operation and maintenance. Regular checking required for *scaling* on protective sleeve. Sufficient pre-treatment is required in order to provide low turbidity for an efficient disinfection.
SOCIAL	Effective treatment option leaving no aesthetic marks in water. Insufficient functioning of UV treatment might result in reactivation of microorganisms, posing health risk to users. Exposure to UV radiation carries the potential hazard of skin and eye damage.
BANGLADESHI APPLICATIONS	SODIS and SORS were used earlier in coastal areas of Bangladesh. During emergency period they were used but due to the limited water and a larger part 5-6 months of the year is monsoon, its use is decreasing.

TR-15 Chlorination

Category	Content
DESCRIPTION	The most widespread disinfection method worldwide. It is often applied as the final purification step after filtration, but it is also possible as an early treatment step. Centralized installations commonly use chlorine gas or solution. In small communities, hypochlorite solutions or tablet might be more reliable. Local production possible with WATA.
APPLICABILITY	Chlorination is an easy and cheap water disinfection method. It can be used at both the household or central level. After dosing the chlorine remains in the water which prevents pathogenic recontamination. If the applied dose is too high, it may have a negative health impact. Limited applicability where users are not (yet) familiar with the method and the related smell.
REQUIREMENTS	The most robust desinfection devices known require injection methods applying venturi-type solutions. These reduced diameter pipes are inserted either in-line or as a by-pass pipe to the mainline. For the in-line solution, the negative pressure created in the venturi-duct 'sucks up' the chlorine solution. On the suction side, a rotameter can be inserted through which the flow of the chlorine solution is visible and it also allows for flow-control. If a by-pass solution is used, then a simple pump needs to preceed the venture pipe. This pump is needed to deliver the flow to the venture pipe. In this scheme it is useful to add a separate chlorine supply and valves at each control point. In household applications, users need to apply the chlorine themselves. This requires basic knowledge on dosing.
FINANCIAL	Low-cost technology both at a central and at household-level. Often there are available supliers locally or at a regional level, implying that the main concern should be to identify the required capacity for a good selection of brand or type.
INSTITUTIONAL	Application of chlorination might be at household level, at small water bodies (e.g. dug wells or small reservoirs) or in a community water system. People working with chlorine need proper training. External support might also include water quality checks.
ENVIRONMENTAL	Environment related issues are estimated to be minimal. No residuals which need to be disposed or treated. Fluctuations in water flow – e.g. as a result of heavy rainfalls - require adjustment in dosing.
TECHNICAL	Several conditions important for operation: minimal 30 minutes contact time, residual chlorine between 0.5 and 5 mg/L, pH <8, turbidity <5NTU but ideally <1NTU. Further: refilling chlorine, adjusting and cleaning chlorinator and checking dosing.
SOCIAL	Chlorine taste and odor in water may require user education on that it is harmless but that chlorine taste alone is no guarantee for safe water. Possible by-products may arise from disinfection. Limited health risk for people working with

	chlorine.
BANGLADESHI APPLICATIONS	Chlorification is applied widely in Bangladesh. Although automated chlorine dosing is reportedly not appropriate and affordable in remote and small village locations, the method has a strong potential for obtaining safe water from arsenic- an dsalt-free sources. Among other methods, piped water supply, rainwater harvesting and well or Pond Sand Filter applications tend to utilize this disinfection option.

TR-16 Boiling

Category	Content
DESCRIPTION	Water is boiled for at least 1 minute with 1 minute extra for every extra 1000m elevation in mountainous areas. The most straightforward disinfection method applicable for the thermal removal of pathogens (bacteria, viruses, protozoa, helminths). More expensive, but more secure to provide safe drinking water.
APPLICABILITY	Boiling is a typical method for household level use. It is mainly used for the disinfection of small quantities of drinking water. It is a simple method, able to realize safe water in areas with mainly contaminated water. The main limitation of boiling is its high energy/fuel requirement.
REQUIREMENTS	The material requirements for boiling are mainly one or several cooking pots. Besides that, boiling consumes a significant amount of fuel. No expert labor is required. But quite some labor from the users is required for boiling the water on a daily basis.
FINANCIAL	Expensive water treatment option. Specific costs depend on fuel source. Collecting fuel might be very time-consuming. Considering other labour activities which could have been done instead of fuel collection, it becomes even more expensive. Pots mostly available in households already.
INSTITUTIONAL	Method is best suitable for application at household level. Central implementation requirements are minimal, people can just starting with it themselves. According to the disadvantages (fuel requirements and time consumption), other treatment options might be advocated rather than boiling.
ENVIRONMENTAL	Depending on the fuel source, boiling of drinking water might pose a significant burden to the environment. High demand for firewood contributes to deforestation. The local availability of fuels highly influence the feasibility of boiling water at any location.
TECHNICAL	Technical specifications for disinfection of water by boiling, differ from boiling water for 1 minute up to 10 minutes. Hot pots need careful handling, in order to avoid burn injuries. Pots and stoves need to be replaced occasionally.
SOCIAL	Taste of water affected because air released from water, might make people less open for boiling. Might be improved by stirring or shaking water after cooling. The waiting time (until the water is cooled) gives some inconvenience. Risk of burn injuries and respiratory infections. Possible discouraging campaign to preserve natural resources.
BANGLADESHI APPLICATIONS	Boiling is a known practice in cities in Bangladesh where people do not trust the municipal supplied treated water. Another known option in Bangladesh is the Chulli pasteurization system, which makes use of wasted heat generated in traditional clay ovens (chullis).

TR-17 Ceramic pot filter

Category	Content
DESCRIPTION	In this household-level method, water is filtered through a ceramic filter media. The porous structure of the filter is achieved by mixing sawdust or another combustible material with arsenic-free clay material prior to the burning/baking process. The CPF is applied primarily for the removal of pathogens and turbidity form (surface) water. Optimally suitable for water with low to moderate turbidity, this method is often combined with a storage device (bucket or similar).
APPLICABILITY	Mainly applicable for household level use where central water treatment is not a feasible option. As it is affordable and requires no additives, it is optimally applicable in poor, remote areas and rural settings. The method is effective for removing pathogens and turbidity, but the initial turbidity should not be too high. If not cleaned regularly, clogging may become problematic.
REQUIREMENTS	Requirements for the ceramic filters are minimal. Arsenic-free clay nad a secure and semi-professional process is required in order to produce CPFs with adequate purificaiton efficiency. During use, limited labor is required: water needs to be poured into the filter, but for the filtering process itself no labor is required.
FINANCIAL	Candle: 15-30 USD, lasting maximum 3 year but usually 0.5-1 year. Replacing element might cost less than USD 5-7. Pot: USD 12 -25, lasting maximum 5 years but usually 1-2 years. Operation costs are minimal, only labor for filling and cleaning. One of the most affordable HWTS methods and ease of production implies that local introduction (manufacturing and distribution) can contribute to increased livelihood.
INSTITUTIONAL	In many developing coutnries, CPF is posbbible to produce locally, but large-scale production is often occurring in small factories. For ensuring production quality, it is important that manufacturing is executed by a certified enterprise. Dissemination is advisable at regional scale. It requires limited institutional capacity, which is mainly in the form of proper user training and periodic monitoring of adequate CPF use.
ENVIRONMENTAL	Ceramic filters are environmentally friendly products. Even after they are replaced, the material will not pose high pressure on environment.
TECHNICAL	Effectiveness depends on pore size and eventual silver impregnation. Production requires arsenic-free clay material. After use of CPF, the deposited material needs to be scrubbed and removed at regular intervals in order to maintain adequate flow-rate. The filter can be efficiently cleaned in boiling water. Periodically replacement of the pot is requires to ensure safe drinking water. Typical flow rates: 0.1-1 L/h for candle filters, 1-3 L/h for pot filters.
SOCIAL	Users only need to pour water into filter. The filtration process is time-consuming, that requires users to adjust their water use to the filter capacity. Configurations with siphon might be more comfortable to apply (filtration rate 4-6 L/h). The user responsibility to regularly clean and replace filter may pose a health risk in the form of unsafe water use.
BANGLADESHI	Ceramic filter mostly used in urban areas of Bangladesh to filter the

APPLICATIONS	WASA/municipal supplied water to remove the suspended solids (turbidity) from boiled water.

TR-18 Infiltration galleries

Category	Content
DESCRIPTION	Similarly to riverbank filtration, infiltration galleries abstract water indirectly from ponds or streams. The method entails the use slotted or perforated pipes which need to be installed under the pond or river bottom for proper filtration of the upper groundwater (from the surface water body). Depending on the required amount of water, the length of the pipe may be several meters up to a few hundred meters. Installation encompasses the placing of the pipe under the riverbed (0.5-1.5m) and the addition of one of more gravel beds for filtration (depending on the composition of the riverbed). Collector well is often a shallow well. Construction mostly occurs at the end of the dry season when water level is lowest.
APPLICABILITY	Infiltration galleries provide a good method to get relatively clean water throughout the year. Applicable for water bodies with no significant contamination. It is an affordable method for communities in the vicinity of contamination-free water bodies. Turbidity level is usually low when compared to surface water values. Main disadvantages are the risk of clogging and the considerable investment costs.
REQUIREMENTS	Main requirements include the cost of pipline, collector well and the construction activities. Local labor is frequyently applied to reduce installation costs. Once constructed the maintenance requirements are minimal.
FINANCIAL	Cost might be about USD400 for some tens of meters or 650 USD for 15 households. Primarily, length of pipe is decisive in the costs. Additional costs include construction and maintenance expenses for the extraction well in the river bank.
INSTITUTIONAL	Infiltration galleries can be implemented from small community-scale to a larger user group level. It can be managed either by a community committee or another local authority. Since maintenance is minimal, institutional requirements are limited.
ENVIRONMENTAL	Location is important as surface water source contaminations may increase the need for purification and construction affects people downstream. Animal husbandry or municipality should be downstream from construction to avoid organic contamination. Upstream activities can still be source of contamination.
TECHNICAL	Installation of drainpipes is advised at least at 1.5m below ground surface and still 1m within saturated zone during dry season. Installation activities include: excavating trench, laying gravel layer, pipe and gravel covering, and the refilling of the trench. During construction, the key considerations include the ensuring of proper filtering (with the help of one or more gravel beddings), the identification of the proper depth of placing (for year-round use), the ensuring of an optimal slope (to prevent sediment buildup in pipes). Key maintenance activity includes the regular cleaning of the collected sediment in the collector well. If abandoned, water discharge rate can significantly drop as a result of accumulated sediment.
SOCIAL	The extracted water might still be contaminated, requiring household-level treatment (disinfection or filtration). This method may result in social friction both because of possible overabstraction and because method is not

	compatible with agricultural or industrial production in vicinity of water source.
BANGLADESHI APPLICATIONS	Infiltration galleries collect water from rivers or lakes. These are in general free of arsenic or salt contaminations. In Bangladesh, several installations are known. Main limitations to application are the limited availability of contamination-free source water and clogging of drainpipes. Examples of organisations working with infiltration galleries are DPHE, SPACE and WaterAid.

TR-19 Riverbank filtration

Category	Content
DESCRIPTION	Riverbank filtration abstracts water from the subsurface near a surface water body like a river or lake. This method is similar to infiltration galleries with the difference that the movement of abstracted water through th subsurface creates not inly a filtering effect, btu a biological purification as well.
APPLICABILITY	Riverbank filtration is an efficient way of obtaining relatively contamination-free water (the method is still applied in several developed countries. Both turbidity and pathogen levels are low compared to surface water.
REQUIREMENTS	Main requirements are the labor and materials for construction. Construction of a community-based riverbank filtration unit might cost 10 working days for 6 laborers. Once constructed the maintenance requirements are minimal. In cease iron or managanese contamination is observed, then additional treatment units need to be installed.
FINANCIAL	Construction costs for 40 households might be about 1300 USD. Additional costs include construction and maintenance expenses for the extraction well in the river bank.
INSTITUTIONAL	This method can be implemented for large-scale use, including small communities to large user group-level. It can be managed either by a community committee or another local authority. Since maintenance is minimal, institutional requirements are limited ot the ensuring of the limiting of local activities that may present a contamination risk of the riverbank area.
ENVIRONMENTAL	Location is important as water source contaminations may increase the need for purification and construction affects people downstream. Animal husbandry, agricultural production or human settlements should be downstream from installation in order to avoid organicor pesticide pollution.
TECHNICAL	The key technical design parameter is the retention time of the filtrated river water in the ground prior to abstraction. Depending on the soil composition and the rate of abstraction, the retention time influences rate of contamination removal in the ground. A typically applicable retention time is in the tens of days, but systems exist with retention times between 5-100 days. Installation includes: excavating trench, laying gravel and pipe for abstraction, and refilling soil. Riverbank filtration has very little maintenance requirements.
SOCIAL	The extracted water might still be contaminated. Lack of central water purification may necessitate household-level treatment/disinfection. Social friction is possible if level of water abstraction significantly reduces available water downstream.
BANGLADESHI APPLICATIONS	Although the similar infiltration galleries are one of the accepted methods in Bangladesh, no application of riverbank filtration is known in the country. This method can offer safe water in most cases. Indian methods may serve as blueprint for implementation. The combined filtration and biological removal makes it a potential method to combine with piped water systems.

7 Additional considerations for the sustainable implementation of water supply methods

7.1 (Un)foreseeable challenges in water sectors

The ASTRA decision-support tool contains water supply and treatment technologies to mitigate arsenic and salinity problems in a Bangladeshi context. The included screening criteria are directly relevant to support sustainable implementations. Based on international experience, the following discussion chapter views and discusses indirect traits that can help reforming the Bangladeshi water sector to create an enabling environment for a higher operational sustainability. This discussion has a broader scope than the ASTRA tool. With its institutional and financial focus, it is meant to frame the ASTRA approach rather than compete with it.

7.1.1 Introduction to a broad decision-making framework

In this sourcebook and decision-support tool, 26 specific water methods are identified as eligible for the Bangladeshi water context. Next to the local information, the information sheets (matrices) of these methods show multidisciplinary considerations. Each of the included disciplines cite directly relevant information, e.g. the included financial aspects relate to specific purchase and O&M costs, for the given water method. This is a just approach as the primary FIETS aspects were shown to be adequate in defining functionality for a sustainable operation.

During the preparation of the ASTRA tool, the key traits of the Bangladeshi water sectors became apparent. It should be stressed that such traits as the (i) limited financing possibilities, (ii) an often restricted level of revenues and (iii) a fluctuating quality of local management are specific not only to Bangladesh but to most asset-poor water sectors of developing countries. These are widespread problems, but fortunately this implies that there are internationally accepted approaches that may help mitigating these challenges.

In this chapter, we discuss such additional – in some way indirect – considerations that should also become relevant to any decision-maker aiming at a sustainable mitigation of water challenges. These considerations go beyond the presented ASTRA strategy as they represent a way of viewing the implementation challenge instead of forming concrete factors in method applicability. The focus of these indirect considerations is on sustainability. It is formulated here as a decision-making framework that views water method implementation within the continuing development of the Bangladeshi water sector.

The rest of this chapter is organized into three thematic sections. The remaining paragraphs in this section detail the relevant features of operational sustainability. The second section deals with the importance of an enabling business-oriented environment for a healthy water sector. The third section discusses the importance of proper institutional supervison and monitoring.

7.1.2 How to approach the development of a resilient water sector

Water supply methods that may be conceived to be optimal solutions today, may not prove resilient in the face of tomorrow's challenges. To offer an example: a large number of yard pumps were introduced in rural Bangladesh in the 90's in order to increase water access. The key considerations for implementation were its features of being a (relatively) cheap and robust solution for middleand low-income communities. Initially, the overall quality of implementation was considered to be a success, but soon after two major problems hindered an overall positive experience.

The first unforeseeable challenge appeared in the form of widespread contaminations in the abstracted water. Next to arsenic, also salinity and heavy metals (iron, managanese) reduced its use as a safe water supply option. A less understood but very persistent effect of this initiative was that the beneficiaries got accustomed to direct water access at the household. Although on-site water supply should always remain a priority, this feature today hinders the successful implementation of less comfortable, but much safer water supply alternatives.

This is what this chapter is about: it does not want to offer more considerations for solving today's water challenges, but explain how certain aspects of professionalization can improve sustainability of current and newly implemented water supply methods. To do that, this chapter handles the two key aspects that are the most relevant for a sectorwide approach. These aspects are business- and policy-related. This financial and institutional focus is justified as the main concerns of sector-wide operational sustainability include (i) the safe ensuring of revenues from water use and (ii) clarification of the appropriate roles of institutions and other actors in the sector.

7.2 Proposed financial considerations for a resilient water sector in Bangladesh

Financing WASH services poses a serious and growing challenge in developing countries. Governments, civil society and communities are struggling with issues as decentralisation, adequate fund allocation and cost recovery. Few countries have realistic operational policies and strategies to enable sustainable financing for increased WASH service coverage, particularly for the poor. To overcome these challenges, market forces must be recognised and appropriately considered.

7.2.1 Increase (local) revenues

A business-oriented water sector is one where even small enterprises have a realistic opportunity to succeed when properly addressing water and sanitation in a locally regulated business sector. Initiatives manage water delivery against a sufficiently high revenue from the serviced public and governments aim at utilizing local finance opportunities and prioritize WASH in their own budgets, using tax revenues for investment.

The above necessitates that emphasis is given to the ensuring of a high return of revenues from water supply. This often seems to be the most challenging activity in water initiatives, despite that there exist a number of approaches that can support high revenues. International experience indicates that high rate of revenues depend primarily on the user acceptance of the water service, which on its turn depends primarily on (i) the type of water delivery and (ii) the reliability of service. i.e. the quality (and quantity) of the delivered water. Former is primarily based on the water method(s) in the supply chain. Latter regards the quality of service in the first place. To offer an example, users may be more appreciative to a regularly offered part-time (daily) supply of water than a 24/7 delivery with long and unforeseeable downtimes. To reformulate: operational sustainability requires a delivery service that can achieve a sufficiently high financial revenue through the delivery of safe water according to the needs of the customers.

An increase in revenues can be achieved through proper financial management that includes a payment aiming at a high level of accountability of the delivered water. There exist various management models that place high importance on their financial system, even above that of the technical settings. This is done in order to ensure an adequate level of returns. In combination with accessible helpdesks to understand and follow user satisfaction, these models are based on a constant monitoring and analysis of user behavior and level of payments.

Regarding sustainable novel payments systems: the dissemination of digital systems is a recent, but fastly growing phenomenon. Worldwide, more and more services are based on this approach. One of the potential forms is to allow water purchase in the framework of a pre-paid system. To offer an example: the NGO *Water Forever International* recently introduced such an approach in the South of Kenya. Their pre-paid hamdpump system is installed at locations of previously failed handpump facilities. After the repairing of these facilities, the NGO adds a meter-system to the handpump that allows water withdrawal based on a card system. The card can be purchased and refilled at local shops. With this system, nearly 100% of the abstracted water is paid and accounted for (Scheurs, 2014). (The only exception is during a breakdown event, when the system allows free water abstraction.)

Such payment systems in the local irrigation sector are already being tried in Bangladesh too (BMDA, 2014). In fact, this Bangladeshi irrigation scheme is already copied by Indian authorities to professionalize their own irrigation sector (Ahuja, 2014). Claims in favor of such pre-paid irrigation designs include not only the increased level of revenues, but that this centralized payment system can reduce risk of overcharging farmers by local operators. As such systems account for all water delivered, the financial balance also becomes transparent.

7.2.2 Novel financial structures

Taxes, transfers and tariffs are the main financing strategies. The three 'T's' is a formulation devised by the Organisation for Economic Cooperation and Development (OECD). The OECD distinguishes these sources from other forms of finance that have to be repaid, such as loans, bonds or equity. According to the OECD (2009): '*Establishing the water sector on a financially sustainable basis requires finding the right mix between the ultimate revenues for the water sector*.' Before the financing sources are discussed, a brief description of these mechanisms is given.

Transfers refer to funds from international donors and charitable foundations (including NGOs, decentralized cooperation or local civil society organizations) that typically come from other countries (WHO, 2012). These funds can be contributed in the form of grants, concessionary loans (i.e. loans that include a *grant*-element in the form of a subsidized interest rate or a grace period) or guarantees.

Tariffs are funds contributed by users of water, sanitation and hygiene services for obtaining the service (WHO, 2012). Users generally make payments to service providers for getting access to the service and for using the service. When the service is self-provided, e.g. when a household builds and operates its own household latrine, or when households try to improve the services they receive, e.g expenses with water purification devices, the equity invested by the household (in the form of cash, material or time, sometimes referred to as 'sweat equity') would also fall under tariffs.

Taxes refer to funds originating from domestic taxes that are channelled to the sector via transfers from all levels of government, including national, regional and local (WHO, 2012). Such funds would typically be provided as subsidies for capital investment or operations. *Hidden* forms of subsidies may include tax rebates, soft loans, e.g. loans at a subsidized interest rate, or subsidized services, e.g. subsidized electricity.

Tariffs are can be optimally applied to cover operations and minor maintenance expenditure and the cost of capital. Transfers are suitable for capital expenditure and indirect support. Taxes are used to cover direct support. In practice, capital maintenance is often underfunded as its expected to be covered by tariffs. However, this is often not the case; resulting in premature failure of the involved infrastructure. Tariffs – in combination with transfers – may provide a feasible solution where taxing water services is a challenging issue.

7.2.2.1 Sources of financing

A long-term financing strategy is essential where the high initial costs of infrastructure projects is coupled to a long service life. In order to cover debt service payments and operational costs by revenues, it is usually necessary for the capital costs of the infrastructure to be spread over many years. This can be achieved through the following strategies:

- Official Development Aid (transfers): In low-income countries, a significant share of funding comes from ODA, mostly in the form of grants.
- A crucial financial challenge in low-income countries is infrastructural co-funding of private stakeholders. In practice, this involvement is often present in some develoing sectors (e.g. ICT), but it is often suboptimal in the water sector. Optimal co-financing is provided in the form of equity or debt invested primarily in large infrastructure projects. The most widespread and efficient form is Public-Private Partnerships (PPP), where the private sector participates directly with the public sector in water projects.
- Banks are limited in their ability to provide long term financing as their major source of funding is short-term deposits. To avoid maturity mismatches banks normally cannot provide loans with tenors of more than five years. If banks receive longer term funding, it is most commonly via long-term loans from development finance institutions (DFIs). When that happens, banks eventually tend to provide longer tenors.
- An important potential source of long term financing for infrastructure are pre-funded pension plans that have experienced rapid growth in many developing countries in recent years. In addition to pension funds, there are other institutional investors, such as insurance companies, mutual funds and other collective investment schemes that may invest in infrastructure projects.

7.2.2.2 Blending of the various financing sources or financing instruments

Local financial institutions typically avoid lending money to the working poor due to their lack of collateral, their credit history and in some cases their limited business track record. Donor funding or philanthropic & development capital is possible to mobilize co-financing from local institutions, encouraging them to lend to the conventionally ‘unbankable’. In fact, this technique utilized in large-scale infrastructure projects can be applied to finance small-scale infrastructure as well.

Ideally, local banks or financiers – in cooperation with the government – are willing to identify local projects, involve private sector parties and prepare ‘bankable solutions’. In practice, however, local banking expertise is often lacking leading to long delays in implementation. This is where donors can play an important role by developing investment incentives to encourage them to get involved. In Bngladesh, this already exists to some extent. The active involvement of micro-financing institutes is a good example of co-financing water projects. Text box 2 offers a concrete example from Kenya.

Maji Ni Maisha: Innovative Finance for Community Water Schemes in Kenya

Introduction and objectives

The Maji Ni Majsha project is about increasing access of rural communities to a clean and reliable water supply in Kenya. The project is financed by a blend of commercial finance and an output-based subsidy of the Worldbank. The project's objective is to help community-based water providers in accessing finance to improve water systems and connect poor households to piped water supply. 'Maji Ni Maisha' means 'Water is Life'.

Concept

The financing concept is blending output-based subsidies and commercial finance. It was the first GPOBA-funded project (Global Partnership on Output-Based Aid) that used this combination. Financing is provided on a project finance basis. The community provides equity (20 percent of project cost) and K-Rep finances the remaining 80 percent through a loan with a maximum tenor of five years. The longer tenor of the loan is made possible through the output-based subsidy which repays up to half of the loan. It also makes the monthly repayments more affordable for the community. The subsidy is output-based: the actual payments depend on target-related performance (i.e. number of connected households).

Main sponsor and stakeholders

The output-based aid is provided by Worldbank's GPOBA. K-Rep bank is providing the loans. The output-based subsidy helped K-Rep to enter the sector. Community-based water service providers develop, a, and manage the water assets. Worldbank's PPIAF finances the grants that enabled the communities to contract consultants for project development.

Scale and specifics of the business model

The total investment is ~US$2 mln and covers five districts around Nairobi. The total grant is US$1.15 mln. Financing for the sub-projects varies from US$60,000 to US$200,000. To reduce the collateral required from the borrowers, K-Rep Bank purchased a partial credit guarantee from USAID's Development Credit Authority to cover 50% of the loan principal.

Success factors

The provision of an output-based subsidy covering part of the loan repayments made it possible to use commercial loans for project financing. Important success factors were:

- Worldbank knowledge, grants and TA enabling private finance
- Blending grants and loans
- K-Reps willingness to enter this new market

Constraints and applicability

- Willingness of commercial banks to enter the market
- Not in all situations is TA and knowledge (from PPIAF) available
- High revenues needed to pay for at least part of the loan repayments + interest

In Bangladesh, a similar approach is justified if the projected revenue collection can attract commercial banks!

Text box 3 Enabling environment: Extension of large infrastructure to underservices areas

7.3 Institutional considerations for a resilient water sector in Bangladesh

In the current framework, the institutional considerations need to ensure that institutions, policies and procedures at the local level are functional and meet the demands of WASH service users. This necessitates households, authorities and service providers at the local and the national level to be clear on their own roles, tasks and responsibilities; so that they are capable of fulfilling these roles effectively and in a transparent fashion.

7.3.1 Diversification of water resources

Access to water has been declared a human right, which entitles everyone to sufficient, safe, acceptable, physically accessible and affordable water for personal, domestic and productive use. Optimally, sustainable water and sanitation access should be achieved without adverse effects on the water catchment area or the environment in the broader sense.

The geographical and socio-economic characteristics of Bangladesh often does not allow this environmental consideration to be valid in water projects. The high population density and the multiple contaminations at many Bangladeshi locations have formed the water sector to rely dominantly on deep groundwater aquifers. As this source can be offered directly without significant costs for treatment, this is a relatively cheap option. More importantly, the lack of need for treatment makes such solutions also very reliable. As there are no failing parts in the treatment process, users learnt to prefer direct abstraction of deep groundwater above all other options.

If Bangladesh wants to secure an environmentally and also economically sustainable water supply, it needs to improve the diversification of its water resources. The Bangladeshi government already integrates this notion in its water policy by motivating alternative resources (primarily surface water) in its water trends. As the national water use does not reflect their efforts, such efforts need to be made more efficient.

To achieve that, the national government and its local representatives need to further specify their legislation. Optimal integration of non-groundwater sources will automatically mean that application of treatments need to get increased attention. Their costs and reliability need to be improved in order to increase their chances of application. Considering that DPHE already functions as a national-level research institute, their efforts may be amplified and expanded. Similar expertise exists at local higher education institutes. Empowering universities to execute pragmatic water research is an efficient strategy to support the development of locally appropriate treatments. With more reliable treatment methods, public opinion can change in favor of non-groundwater solutions, possibly with less efforts than what is being spent at present. An additional advantage of this approach is the education of local experts who can enter the sector with state-of-the-art knowledge on the appropriate application of treatment methods.

A key reason to omit treatments is the additional cost when compared to direct abstraction. The treatment methods in the ASTRA tool show that there is a wide price range to treat arsenic and salinity alone. Choosing cheaper treatments may solve some of the cost issues. Another effect that can work in the favor of affordable treatments is their wider application. Frequent implementation is likely to generate a local market and manufacturing sector that can supply parts cheaper and with the utilization of local economy and labor. Although it is not expected to lead to cheaper solutions that e.g. a deep tube well solution, the reduced costs may become affordable on a setoral level in the long term.

7.3.2 Reduction of water conflicts

The Bangladeshi water sector has to comply with the human right to water and the climate change imposed changes. This is increasingly difficult because of the high population density and the fast shrinking of the available water pool in the country. A potential option to approach these challenges is to ascribe an economic value to water access. Some potentially appropriate financing mechanisms were already advocated in the previous section. This section argues that with proper water stewardship, these economic solutions can be turned into policy mechanisms for the reduction of water conflicts.

High revenues were shown to be a prerequisite to a sustainable water sector. They are also a prerequisite to the optimal sharing of the restricted amount of safe water available. . Institutions and decision-makers have a crucial role in the determining and forming of this 'economization' of water access. If coupled to a social distribution of the revenues (at a sectoral level), decision-makers could improve the inclusion of otherwise disadvantaged groups (rural poor, women, children or elders) and even have some control over water scarcity. By creating an economically transparent environment where water costs are well defined and properly communicated, a higher water use would logically turn into higher economic activity and more revenues for the sector. Cross-subsidizing for example irrigation water profits to specific low-income groups could not only provide a more social water acess, but may even lead to economic benefits. Improved water access on a large-scale is likely to lead to significant improvements in public health, wealth and wellbeing, which could manifest in lower costs in the health sector.

7.3.3 Allocation of water supply ownership

Responsibility and accountability play a major role in the provision of safe drinking water. This is especially when the source water may contain contaminations of high health risks such as arsenic. When designing a water access solution, it would be advantageous to view this aspect of the initiative. In case of urban, centralized piped water system, professional management is hardly eveer an issue in Bangladesh. However, decentralized solutions for peri-urban and rual areas often suffer from suboptimal management. In case of small grid solutions, local committees need to manage available resources to maintain operations and household-level solutions are handled by the household memebers themselves. The following Table 26 indicates what consequences will arise depending on the responsibility to deliver safe drinking water to the households.

Table 26 Overview of water supply responsibility and its institutional and financing consequences

Responsibility	Characteristics	Sustainability & development	Financing aspects
Household level (e.g. HWTS, bottled water)	Immediate solution, transaction between household and supplier. Sales or service models apply.	Minimal. High risk that households neglect devices/services in favor of free alternatives. Monitoring is inefficient, chance of innovation is limited.	Upfront investment minimal. Maybe limited funds required for start-up, then mainly financed by tariffs.
Local committee (Small scale piped / small grid solutions)	Sustainability possible only in combination with 'service model', therefore they need functioning local organisation (systems), moderate complexity.	More control on the whole chain (from water source up to quality of drinking water). Systems can be improved: technology, price – performance, etc. Monitoring on service levels is possible.	Upfront investments required necessitating involvement of financiers required.
Professional management (Urban piped water systems)	Only as a long-term, large-scale solution. Sustainability only possible if well organised systems are in place.	Same as in 'small grid' systems, but due to larger scale, most likely best price per service unit, highest performance and service levels.	Significant upfront investments and pre-financing required. Therefore involvement of strong financiers required, e.g. pension funds, insurance companies.

In the table, innovation possibilities are given to be limited for household-level solutions. If the household is responsible for the management , then any innovation and quality maintenance depends on the household's capacity. It can be argued that the responsibility for safe drinking water cannot be shifted to households as they have limited awareness for the severity of the issues and/or limited finances to afford safe water providing options.

Investing in 'small grid' solutions may have several benefits when it comes to responsibility:

- Service model: responsibility for the quality of the water is with the supplier and the clients pays for the service (rather than recurrent payment for equipment and filters at the household-level).
- Monitoring and control: although the services itself can be provided by private companies, the government has a clear role in monitoring and control along the whole chain. The government can provide licenses and agree upon minimum 'service levels'.
- Innovation: if properly organised and e.g. private companies can compete for 'licenses', they can be encouraged to come up with innovations and solutions to further improve price-performance or to propose solutions on issues in that community.

However, unfortunately, financing of small grid solutions are not yet straightforward to apply. The impediments are related to the "municipality focus'. In many countries the fiscal transfers from the central government are limited, while donors either prefer to deal directly with the central governments or prefer to work at community level. Bangladeshi water institutions need to develop legislative and financial incentives for financiers to pre-finance small grid capital expenditures and initial operating expenditures.

Urban piped water systems are managed by water professionals throughout Bangladesh. The provided water quality and quantity may fluctuate sometimes, but in general these solutions can offer the highest quality of stewardship. However, these large grid solutions require massive investments and involvement of the central government in decision making and fiscal transfers. In practice, excluded groups have limited possibilities to enjoy such professional networks. The only exception for benefit peri-urban or rural groups is to expand the already available network. Some donors like the World Bank have specific programs promoting these type of extensions where possible (see GPOBA example in previous section).

7.4 Key considerations

This chapter discussed key traits in water sector projects that need to be made a priority for the development of a sustainable water sector. These financial and institutional considerations should frame the decision-making process of ASTRA users. The following shortlist offers a summarized version to the discussed topics:

- Novel financing structures need to be explored. State subsidies should be utilized to function as a leverage for commercial financing from banks to make pro-poor investments viable and attract equity from communities. The investments financed with commercial loans should generate revenue within a relatively short period of time, and outputs linked to the subsidy payment need to be achievable in a timely manner. Consideration should be given to institutionalizing the support mechanisms necessary to further develop such financing approaches.
- Local financing of water initiatives is crucial for operational sustainability. This implies that target communities must be willing to pay for the offered services. Although this is likely to lead to a diversification of water supply methods, the expected higher rate of paid water can support the further professionalization of the water sector.
- State authorities should invest in local capacity to ensure that management is sufficiently professional for the maintenance of a good quality water service. International experience suggests this to be a key prerequisite to ensure high revenues from the delivered water.
- The Bangladeshi government’s concern that groundwater is overabstracted should be addressed in each water project. Despite the general public preference for groundwater, engineers and decision-makers should strive to utilize alternative (more sustainable) water sources.
- Ensuring high revenues from water delivery is shown to be essential for the operational sustainability of water services. A standard payment scheme may even contribute to a more efficient use of this natural resource and lessen water stress and conflicts. However, this aspect should be considered carefully. A novel revenue policy should not lead to the exclusion of low-income users from safe water access.
- The responsibility for the ensuring of safe water should be carefully designed in the project planning phase. It is not realistic to expect that high risk contaminations – as for example arsenic – are sufficiently removed by the water users with the help of HWTS methods.

8 Final remarks

It is the goal of the authors that the presented tool and its content can contribute to positive changes in the Bangladeshi water sector. The feature to offer both fundamental knowledge for in-depth understanding and practical information on eligibility and boundaries is expected to make the tool optimal for aiding appropriate mitigation strategies. Important to note, that especially the practical, compendium-type section of the book is susceptible to changes in price, social habits and local developments.

Organizations utilizing the ASTRA tool may consider the updating and expanding of the current content with new data, based on their own experiences. Despite the extensive literature search and the executed interviews, limitations in data availability are most prevalent when it comes to reasons of failure. It is hypothesized that such information is not published or shared extensively because it may reflect negatively on the involved organizations. Although this understandable in relation to donors who only want to finance successful projects, but it seriously limits innovation. There is lot to learn from failures, both by the water sector and the users of the tools. As a result, similar mistakes are prone to repetition over time to further drain donor assets. Users of the ASTRA tool are therefore encouraged to keep registering positive and negative experiences on method resilience according to the structure of the technological sheets. If properly done, they can build a valuable knowledge base for own use or share the information for common learning.

Should the book achieve its key purpose and result in more rational implementation of arsenic- and salt-mitigating options, then it is necessary to keep maintaining the quality of information contained. Therefore, the organization(s) utilizing the book are encouraged to regularly review and update its information both from theory (especially concerning new developments) but primarily from the field. The establishing of an online portal to share tool information and interactively update content may be a beneficial option in this regard.

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10 Annexes

ANNEX 1 Eligibility matrices of the ASTRA tool

ANNEX 2 Inventory of the interviewed organizations and their profiles

Annex 1 Eligibility matrices of the ASTRA tool

SD-01 Deep and intermediate tube well

WATER SOURCE	Rainwater	Surface water	Brackish water	Groundwater	
REMOVAL	Arsenic	Salts			
LOCATION	Densely populated urban	Densely populated, low-income urban	Moderately populated urban	Peri-urban, rural	Rural, remote
ZONE IN BANGLADESH	Flood plain	Low water table area	Coastal zone	Low lying area / basin	Hilly region
SCALE OF IMPLEMENTATION	Household	Shared	Small community	School or institution	Large user group
PREFERRED LEVEL OF WATER DELIVERY	Household	Shared	Small community	School or institution	Large user group
PREFERRED MANAGEMENT LEVEL	Household	Shared	Small community	Municipal	
STATUS IN BANGLADESH	Widespread	Known	Little known	Unknown	
SYSTEM SOPHISTICATION	Labor-intensive	Intermediate	Technology-intensive		
GROUND FORMATION	Sand & gravel	Clay formations	Compacted formations	Soft weathered rock	Bedrock
WATER LIFTING	Not required	0-8 m	8-15 m	15-40 m	> 40 m
ENERGY AVAILABLE	None	Electricity grid	Fuel generated	Solar energy	Wind energy
FLOOD DANGER	Not affected	Only flooded in extreme weather	Annually affected by floods		
ACCESS TO SITE	On parcel	Outside of household area	Less than 10 minutes to access	Less than 30 minutes to access	More than 30 minutes to access
CONSTRUCTION COSTS	Negligible	Less than USD25	USD25-100	USD100-1,000	More than USD1,000
MAINTENANCE COSTS	Negligible	Less than USD5 per month	More than USD5 per months	More than USD100 per month	
TIME NEEDED TO CONSTRUCT	Insignificant	A few hours	A day	Several days to a week	Weeks
LEVEL OF EXPERTISE IN O&M	Unskilled	Local technician	Local government	External experts	
USER ACCEPTANCE	No activity	Limited extension	Considerable extension	Extensive campaign	

SD-02 Dug well

WATER SOURCE	Rainwater	Surface water	Brackish water	Groundwater	
REMOVAL/MITIGATION	Arsenic	Salts			
LOCATION	Densely populated urban	Densely populated, low-income urban	Moderately populated urban	Peri-urban, rural	Rural, remote
ZONE IN BANGLADESH	Flood plain	Low water table area	Coastal zone	Low lying area / basin	Hilly region
SCALE OF IMPLEMENTATION	Household	Shared	Small community	School or institution	Large user group
PREFERRED LEVEL OF WATER DELIVERY	Household	Shared	Small community	School or institution	Large user group
PREFERRED MANAGEMENT LEVEL	Household	Shared	Small community	Municipal	
STATUS IN BANGLADESH	Widespread	Known	Little known	Unknown	
SYSTEM SOPHISTICATION	Labor-intensive	Intermediate	Technology-intensive		
GROUND FORMATION	Sand & gravel	Clay formations	Compacted formations	Soft weathered rock	Bedrock
WATER LIFTING	Not required	0-8 m	8-15 m	15-40 m	> 40 m
ENERGY AVAILABLE	None	Electricity grid	Fuel generated	Solar energy	Wind energy
FLOOD DANGER	Not affected	Only flooded in extreme weather	Annually affected by floods		
ACCESS TO SITE	On parcel	Outside of household area	Less than 10 minutes to access	Less than 30 minutes to access	More than 30 minutes to access
CONSTRUCTION COSTS	Negligible	Less than USD25	USD25-100	USD100-1,000	More than USD1,000
MAINTENANCE COSTS	Negligible	Less than USD5 per month	More than USD5 per months	More than USD100 per month	
TIME NEEDED TO CONSTRUCT	Insignificant	A few hours	A day	Several days to a week	Weeks
LEVEL OF EXPERTISE IN O&M	Unskilled	Local technician	Local government	External experts	
USER ACCEPTANCE	No activity	Limited extension	Considerable extension	Extensive campaign	

SD-03 Shallow and shrouded tube wells

WATER SOURCE	Rainwater	Surface water	Brackish water	Groundwater	
MITIGATION	Arsenic	Salts			
LOCATION	Densely populated urban	Densely populated, low-income urban	Moderately populated urban	Peri-urban, rural	Rural, remote
ZONE IN BANGLADESH	Flood plain	Low water table area	Coastal zone	Low lying area / basin	Hilly region
SCALE OF IMPLEMENTATION	Household	Shared	Small community	School or institution	Large user group
PREFERRED LEVEL OF WATER DELIVERY	Household	Shared	Small community	School or institution	Large user group
PREFERRED MANAGEMENT LEVEL	Household	Shared	Small community	Municipal	
STATUS IN BANGLADESH	Widespread	Known	Little known	Unknown	
SYSTEM SOPHISTICATION	Labor-intensive	Intermediate	Technology-intensive		
GROUND FORMATION	Sand & gravel	Clay formations	Compacted formations	Soft weathered rock	Bedrock
WATER LIFTING	Not required	0-8 m	8-15 m	15-40 m	> 40 m
ENERGY AVAILABLE	None	Electricity grid	Fuel generated	Solar energy	Wind energy
FLOOD DANGER	Not affected	Only flooded in extreme weather	Annually affected by floods		
ACCESS TO SITE	On parcel	Outside of household area	Less than 10 minutes to access	Less than 30 minutes to access	More than 30 minutes to access
CONSTRUCTION COSTS	Negligible	Less than USD25	USD25-100	More than USD100	
MAINTENANCE COSTS	Negligible	Less than USD5 per month	More than USD5 per months	USD100-1,000	More than USD1,000
TIME NEEDED TO CONSTRUCT	Insignificant	A few hours	A day	Several days to a week	Weeks
LEVEL OF EXPERTISE IN O&M	Unskilled	Local technician	Local government	External experts	
USER ACCEPTANCE	No activity	Limited extension	Considerable extension	Extensive campaign	

SD-04 Well switching

WATER SOURCE	Rainwater	Surface water	Brackish water	Groundwater	
MITIGATION	Arsenic	Salts			
LOCATION	Densely populated urban	Densely populated, low-income urban	Moderately populated urban	Peri-urban, rural	Rural, remote
ZONE IN BANGLADESH	Flood plain	Low water table area	Coastal zone	Low lying area / basin	Hilly region
SCALE OF IMPLEMENTATION	Household	Shared	Small community	School or institution	Large user group
PREFERRED LEVEL OF WATER DELIVERY	Household	Shared	Small community	School or institution	Large user group
PREFERRED MANAGEMENT LEVEL	Household	Shared	Small community	Municipal	
STATUS IN BANGLADESH	Widespread	Known	Little known	Unknown	
SYSTEM SOPHISTICATION	Labor-intensive	Intermediate	Technology-intensive		
GROUND FORMATION	Sand & gravel	Clay formations	Compacted formations	Soft weathered rock	Bedrock
WATER LIFTING	Not required	0-8 m	8-15 m	15-40 m	> 40 m
ENERGY AVAILABLE	None	Electricity grid	Fuel generated	Solar energy	Wind energy
FLOOD DANGER	Not affected	Only flooded in extreme weather	Annually affected by floods		
ACCESS TO SITE	On parcel	Outside of household area	Less than 10 minutes to access	Less than 30 minutes to access	More than 30 minutes to access
CONSTRUCTION COSTS	Negligible	Less than USD25	USD25-100	USD100-1,000	More than USD1,000
MAINTENANCE COSTS	Negligible	Less than USD5 per month	More than USD5 per months	More than USD100 per month	
TIME NEEDED TO CONSTRUCT	Insignificant	A few hours	A day	Several days to a week	Weeks
LEVEL OF EXPERTISE IN O&M	Unskilled	Local technician	Local government	External experts	
USER ACCEPTANCE	No activity	Limited extension	Considerable extension	Extensive campaign	

SD-05 Rainwater harvesting and storage

WATER SOURCE	Rainwater	Surface water	Brackish water	Groundwater	
MITIGATION	Arsenic	Salts			
LOCATION	Densely populated urban	Densely populated, low-income urban	Moderately populated urban	Peri-urban, rural	Rural, remote
ZONE IN BANGLADESH	Flood plain	Low water table area	Coastal zone	Low lying area / basin	Hilly region
SCALE OF IMPLEMENTATION	Household	Shared	Small community	School or institution	Large user group
PREFERRED LEVEL OF WATER DELIVERY	Household	Shared	Small community	School or institution	Large user group
PREFERRED MANAGEMENT LEVEL	Household	Shared	Small community	Municipal	
STATUS IN BANGLADESH	Widespread	Known	Little known	Unknown	
SYSTEM SOPHISTICATION	Labor-intensive	Intermediate	Technology-intensive		
GROUND FORMATION	Sand & gravel	Clay formations	Compacted formations	Soft weathered rock	Bedrock
WATER LIFTING	Not required	0-8 m	8-15 m	15-40 m	> 40 m
ENERGY AVAILABLE	None	Electricity grid	Fuel generated	Solar energy	Wind energy
FLOOD DANGER	Not affected	Only flooded in extreme weather	Annually affected by floods		
ACCESS TO SITE	On parcel	Outside of household area	Less than 10 minutes to access	Less than 30 minutes to access	More than 30 minutes to access
CONSTRUCTION COSTS	Negligible	Less than USD25	USD25-100	More than USD100	
MAINTENANCE COSTS	Negligible	Less than USD5 per month	More than USD5 per months	USD100-1,000	More than USD1,000
TIME NEEDED TO CONSTRUCT	Insignificant	A few hours	A day	Several days to a week	Weeks
LEVEL OF EXPERTISE IN O&M	Unskilled	Local technician	Local government	External experts	
USER ACCEPTANCE	No activity	Limited extension	Considerable extension	Extensive campaign	

SD-06 Managed aquifer recharge

WATER SOURCE	Rainwater	Surface water	Brackish water	Groundwater	
MITIGATION	Arsenic	Salts			
LOCATION	Densely populated urban	Densely populated, low-income urban	Moderately populated urban	Peri-urban, rural	Rural, remote
ZONE IN BANGLADESH	Flood plain	Low water table area	Coastal zone	Low lying area / basin	Hilly region
SCALE OF IMPLEMENTATION	Household	Shared	Small community	School or institution	Large user group
PREFERRED LEVEL OF WATER DELIVERY	Household	Shared	Small community	School or institution	Large user group
PREFERRED MANAGEMENT LEVEL	Household	Shared	Small community	Municipal	
STATUS IN BANGLADESH	Widespread	Known	Little known	Unknown	
SYSTEM SOPHISTICATION	Labor-intensive	Intermediate	Technology-intensive		
GROUND FORMATION	Sand & gravel	Clay formations	Compacted formations	Soft weathered rock	Bedrock
WATER LIFTING	Not required	0-8 m	8-15 m	15-40 m	> 40 m
ENERGY AVAILABLE	None	Electricity grid	Fuel generated	Solar energy	Wind energy
FLOOD DANGER	Not affected	Only flooded in extreme weather	Annually affected by floods		
ACCESS TO SITE	On parcel	Outside of household area	Less than 10 minutes to access	Less than 30 minutes to access	More than 30 minutes to access
CONSTRUCTION COSTS	Negligible	Less than USD25	USD25-100	USD100-1,000	More than USD1,000
MAINTENANCE COSTS	Negligible	Less than USD5 per month	More than USD5 per months	More than USD100 per month	
TIME NEEDED TO CONSTRUCT	Insignificant	A few hours	A day	Several days to a week	Weeks
LEVEL OF EXPERTISE IN O&M	Unskilled	Local technician	Local government	External experts	
USER ACCEPTANCE	No activity	Limited extension	Considerable extension	Extensive campaign	

CO-01 Piped water supply schemes

WATER SOURCE	Rainwater	Surface water	Brackish water	Groundwater	
MITIGATION	Arsenic	Salts			
LOCATION	Densely populated urban	Densely populated, low-income urban	Moderately populated urban	Peri-urban, rural	Rural, remote
ZONE IN BANGLADESH	Flood plain	Low water table area	Coastal zone	Low lying area / basin	Hilly region
SCALE OF IMPLEMENTATION	Household	Shared	Small community	School or institution	Large user group
PREFERRED LEVEL OF WATER DELIVERY	Household	Shared	Small community	School or institution	Large user group
PREFERRED MANAGEMENT LEVEL	Household	Shared	Small community	Municipal	
STATUS IN BANGLADESH	Widespread	Known	Little known	Unknown	
SYSTEM SOPHISTICATION	Labor-intensive	Intermediate	Technology-intensive		
GROUND FORMATION	Sand & gravel	Clay formations	Compacted formations	Soft weathered rock	Bedrock
WATER LIFTING	Not required	0-8 m	8-15 m	15-40 m	> 40 m
ENERGY AVAILABLE	None	Electricity grid	Fuel generated	Solar energy	Wind energy
FLOOD DANGER	Not affected	Only flooded in extreme weather	Annually affected by floods		
ACCESS TO SITE	On parcel	Outside of household area	Less than 10 minutes to access	Less than 30 minutes to access	More than 30 minutes to access
CONSTRUCTION COSTS	Negligible	Less than USD25	USD25-100	USD100-1,000	More than USD1,000
MAINTENANCE COSTS	Negligible	Less than USD5 per month	More than USD5 per months	More than USD100 per month	
TIME NEEDED TO CONSTRUCT	Insignificant	A few hours	A day	Several days to a week	Weeks
LEVEL OF EXPERTISE IN O&M	Unskilled	Local technician	Local government	External experts	
USER ACCEPTANCE	No activity	Limited extension	Considerable extension	Extensive campaign	

TR-01 Chemical oxidation

WATER SOURCE	Rainwater	Surface water	Brackish water	Groundwater	
MITIGATION	Arsenic	Salts			
LOCATION	Densely populated urban	Densely populated, low-income urban	Moderately populated urban	Peri-urban, rural	Rural, remote
ZONE IN BANGLADESH	Flood plain	Low water table area	Coastal zone	Low lying area / basin	Hilly region
SCALE OF IMPLEMENTATION	Household	Shared	Small community	School or institution	Large user group
PREFERRED LEVEL OF WATER DELIVERY	Household	Shared	Small community	School or institution	Large user group
PREFERRED MANAGEMENT LEVEL	Household	Shared	Small community	Municipal	
STATUS IN BANGLADESH	Widespread	Known	Little known	Unknown	
SYSTEM SOPHISTICATION	Labor-intensive	Intermediate	Technology-intensive		
GROUND FORMATION	Sand & gravel	Clay formations	Compacted formations	Soft weathered rock	Bedrock
WATER LIFTING	Not required	0-8 m	8-15 m	15-40 m	> 40 m
ENERGY AVAILABLE	None	Electricity grid	Fuel generated	Solar energy	Wind energy
FLOOD DANGER	Not affected	Only flooded in extreme weather	Annually affected by floods		
ACCESS TO SITE	On parcel	Outside of household area	Less than 10 minutes to access	Less than 30 minutes to access	More than 30 minutes to access
CONSTRUCTION COSTS	Negligible	Less than USD25	USD25-100	USD100-1000	More than USD1,000
MAINTENANCE COSTS	Negligible	Less than USD5 per month	More than USD5 per months	More than USD100 per month	
TIME NEEDED TO CONSTRUCT	Insignificant	A few hours	A day	Several days to a week	Weeks
LEVEL OF EXPERTISE IN O&M	Unskilled	Local technician	Local government	External experts	
USER ACCEPTANCE	No activity	Limited extension	Considerable extension	Extensive campaign	

TR-02 Photo-catalytic oxidation

WATER SOURCE	Rainwater	Surface water	Brackish water	Groundwater	
MITIGATION	Arsenic	Salts			
LOCATION	Densely populated urban	Densely populated, low-income urban	Moderately populated urban	Peri-urban, rural	Rural, remote
ZONE IN BANGLADESH	Flood plain	Low water table area	Coastal zone	Low lying area / basin	Hilly region
SCALE OF IMPLEMENTATION	Household	Shared	Small community	School or institution	Large user group
PREFERRED LEVEL OF WATER DELIVERY	Household	Shared	Small community	School or institution	Large user group
PREFERRED MANAGEMENT LEVEL	Household	Shared	Small community	Municipal	
STATUS IN BANGLADESH	Widespread	Known	Little known	Unknown	
SYSTEM SOPHISTICATION	Labor-intensive	Intermediate	Technology-intensive		
GROUND FORMATION	Sand & gravel	Clay formations	Compacted formations	Soft weathered rock	Bedrock
WATER LIFTING	Not required	0-8 m	8-15 m	15-40 m	> 40 m
ENERGY AVAILABLE	None	Electricity grid	Fuel generated	Solar energy	Wind energy
FLOOD DANGER	Not affected	Only flooded in extreme weather	Annually affected by floods		
ACCESS TO SITE	On parcel	Outside of household area	Less than 10 minutes to access	Less than 30 minutes to access	More than 30 minutes to access
CONSTRUCTION COSTS	Negligible	Less than USD25	USD25-100	USD100-1000	More than USD1,000
MAINTENANCE COSTS	Negligible	Less than USD5 per month	More than USD5 per months	More than USD100 per month	
TIME NEEDED TO CONSTRUCT	Insignificant	A few hours	A day	Several days to a week	Weeks
LEVEL OF EXPERTISE IN O&M	Unskilled	Local technician	Local government	External experts	
USER ACCEPTANCE	No activity	Limited extension	Considerable extension	Extensive campaign	

TR-03 Conventional coagulation, filtration

WATER SOURCE	Rainwater	Surface water	Brackish water	Groundwater	
MITIGATION	Arsenic	Salts			
LOCATION	Densely populated urban	Densely populated, low-income urban	Moderately populated urban	Peri-urban, rural	Rural, remote
ZONE IN BANGLADESH	Flood plain	Low water table area	Coastal zone	Low lying area / basin	Hilly region
SCALE OF IMPLEMENTATION	Household	Shared	Small community	School or institution	Large user group
PREFERRED LEVEL OF WATER DELIVERY	Household	Shared	Small community	School or institution	Large user group
PREFERRED MANAGEMENT LEVEL	Household	Shared	Small community	Municipal	
STATUS IN BANGLADESH	Widespread	Known	Little known	Unknown	
SYSTEM SOPHISTICATION	Labor-intensive	Intermediate	Technology-intensive		
GROUND FORMATION	Sand & gravel	Clay formations	Compacted formations	Soft weathered rock	Bedrock
WATER LIFTING	Not required	0-8 m	8-15 m	15-40 m	> 40 m
ENERGY AVAILABLE	None	Electricity grid	Fuel generated	Solar energy	Wind energy
FLOOD DANGER	Not affected	Only flooded in extreme weather	Annually affected by floods		
ACCESS TO SITE	On parcel	Outside of household area	Less than 10 minutes to access	Less than 30 minutes to access	More than 30 minutes to access
CONSTRUCTION COSTS	Negligible	Less than USD25	USD25-100	USD100-1000	More than USD1,000
MAINTENANCE COSTS	Negligible	Less than USD5 per month	More than USD5 per months	More than USD100 per month	
TIME NEEDED TO CONSTRUCT	Insignificant	A few hours	A day	Several days to a week	Weeks
LEVEL OF EXPERTISE IN O&M	Unskilled	Local technician	Local government	External experts	
USER ACCEPTANCE	No activity	Limited extension	Considerable extension	Extensive campaign	

TR-04 Electrocoagulation

WATER SOURCE	Rainwater	Surface water	Brackish water	Groundwater	
MITIGATION	Arsenic	Salts			
LOCATION	Densely populated urban	Densely populated, low-income urban	Moderately populated urban	Peri-urban, rural	Rural, remote
ZONE IN BANGLADESH	Flood plain	Low water table area	Coastal zone	Low lying area / basin	Hilly region
SCALE OF IMPLEMENTATION	Household	Shared	Small community	School or institution	Large user group
PREFERRED LEVEL OF WATER DELIVERY	Household	Shared	Small community	School or institution	Large user group
PREFERRED MANAGEMENT LEVEL	Household	Shared	Small community	Municipal	
STATUS IN BANGLADESH	Widespread	Known	Little known	Unknown	
SYSTEM SOPHISTICATION	Labor-intensive	Intermediate	Technology-intensive		
GROUND FORMATION	Sand & gravel	Clay formations	Compacted formations	Soft weathered rock	Bedrock
WATER LIFTING	Not required	0-8 m	8-15 m	15-40 m	> 40 m
ENERGY AVAILABLE	None	Electricity grid	Fuel generated	Solar energy	Wind energy
FLOOD DANGER	Not affected	Only flooded in extreme weather	Annually affected by floods		
ACCESS TO SITE	On parcel	Outside of household area	Less than 10 minutes to access	Less than 30 minutes to access	More than 30 minutes to access
CONSTRUCTION COSTS	Negligible	Less than USD25	USD25-100	USD100-1000	More than USD1,000
MAINTENANCE COSTS	Negligible	Less than USD5 per month	More than USD5 per months	More than USD100 per month	
TIME NEEDED TO CONSTRUCT	Insignificant	A few hours	A day	Several days to a week	Weeks
LEVEL OF EXPERTISE IN O&M	Unskilled	Local technician	Local government	External experts	
USER ACCEPTANCE	No activity	Limited extension	Considerable extension	Extensive campaign	

TR-05 Iron or aluminium oxide based adsorption

WATER SOURCE	Rainwater	Surface water	Brackish water	Groundwater	
MITIGATION	Arsenic	Salts			
LOCATION	Densely populated urban	Densely populated, low-income urban	Moderately populated urban	Peri-urban, rural	Rural, remote
ZONE IN BANGLADESH	Flood plain	Low water table area	Coastal zone	Low lying area / basin	Hilly region
SCALE OF IMPLEMENTATION	Household	Shared	Small community	School or institution	Large user group
PREFERRED LEVEL OF WATER DELIVERY	Household	Shared	Small community	School or institution	Large user group
PREFERRED MANAGEMENT LEVEL	Household	Shared	Small community	Municipal	
STATUS IN BANGLADESH	Widespread	Known	Little known	Unknown	
SYSTEM SOPHISTICATION	Labor-intensive	Intermediate	Technology-intensive		
GROUND FORMATION	Sand & gravel	Clay formations	Compacted formations	Soft weathered rock	Bedrock
WATER LIFTING	Not required	0-8 m	8-15 m	15-40 m	> 40 m
ENERGY AVAILABLE	None	Electricity grid	Fuel generated	Solar energy	Wind energy
FLOOD DANGER	Not affected	Only flooded in extreme weather	Annually affected by floods		
ACCESS TO SITE	On parcel	Outside of household area	Less than 10 minutes to access	Less than 30 minutes to access	More than 30 minutes to access
CONSTRUCTION COSTS	Negligible	Less than USD25	USD25-100	USD100-1000	More than USD1,000
MAINTENANCE COSTS	Negligible	Less than USD5 per month	More than USD5 per months	More than USD100 per month	
TIME NEEDED TO CONSTRUCT	Insignificant	A few hours	A day	Several days to a week	Weeks
LEVEL OF EXPERTISE IN O&M	Unskilled	Local technician	Local government	External experts	
USER ACCEPTANCE	No activity	Limited extension	Considerable extension	Extensive campaign	

TR-06 Zerovalent iron adsorption

WATER SOURCE	Rainwater	Surface water	Brackish water	Groundwater	
MITIGATION	Arsenic	Salts			
LOCATION	Densely populated urban	Densely populated, low-income urban	Moderately populated urban	Peri-urban, rural	Rural, remote
ZONE IN BANGLADESH	Flood plain	Low water table area	Coastal zone	Low lying area / basin	Hilly region
SCALE OF IMPLEMENTATION	Household	Shared	Small community	School or institution	Large user group
PREFERRED LEVEL OF WATER DELIVERY	Household	Shared	Small community	School or institution	Large user group
PREFERRED MANAGEMENT LEVEL	Household	Shared	Small community	Municipal	
STATUS IN BANGLADESH	Widespread	Known	Little known	Unknown	
SYSTEM SOPHISTICATION	Labor-intensive	Intermediate	Technology-intensive		
GROUND FORMATION	Sand & gravel	Clay formations	Compacted formations	Soft weathered rock	Bedrock
WATER LIFTING	Not required	0-8 m	8-15 m	15-40 m	> 40 m
ENERGY AVAILABLE	None	Electricity grid	Fuel generated	Solar energy	Wind energy
FLOOD DANGER	Not affected	Only flooded in extreme weather	Annually affected by floods		
ACCESS TO SITE	On parcel	Outside of household area	Less than 10 minutes to access	Less than 30 minutes to access	More than 30 minutes to access
CONSTRUCTION COSTS	Negligible	Less than USD25	USD25-100	USD100-1000	More than USD1,000
MAINTENANCE COSTS	Negligible	Less than USD5 per month	More than USD5 per months	More than USD100 per month	
TIME NEEDED TO CONSTRUCT	Insignificant	A few hours	A day	Several days to a week	Weeks
LEVEL OF EXPERTISE IN O&M	Unskilled	Local technician	Local government	External experts	
USER ACCEPTANCE	No activity	Limited extension	Considerable extension	Extensive campaign	

TR-07 NF and low-pressure reverse osmosis

WATER SOURCE	Rainwater	Surface water	Brackish water	Groundwater	
MITIGATION	Arsenic	Salts			
LOCATION	Densely populated urban	Densely populated, low-income urban	Moderately populated urban	Peri-urban, rural	Rural, remote
ZONE IN BANGLADESH	Flood plain	Low water table area	Coastal zone	Low lying area / basin	Hilly region
SCALE OF IMPLEMENTATION	Household	Shared	Small community	School or institution	Large user group
PREFERRED LEVEL OF WATER DELIVERY	Household	Shared	Small community	School or institution	Large user group
PREFERRED MANAGEMENT LEVEL	Household	Shared	Small community	Municipal	
STATUS IN BANGLADESH	Widespread	Known	Little known	Unknown	
SYSTEM SOPHISTICATION	Labor-intensive	Intermediate	Technology-intensive		
GROUND FORMATION	Sand & gravel	Clay formations	Compacted formations	Soft weathered rock	Bedrock
WATER LIFTING	Not required	0-8 m	8-15 m	15-40 m	> 40 m
ENERGY AVAILABLE	None	Electricity grid	Fuel generated	Solar energy	Wind energy
FLOOD DANGER	Not affected	Only flooded in extreme weather	Annually affected by floods		
ACCESS TO SITE	On parcel	Outside of household area	Less than 10 minutes to access	Less than 30 minutes to access	More than 30 minutes to access
CONSTRUCTION COSTS	Negligible	Less than USD25	USD25-100	USD100-1000	More than USD1,000
MAINTENANCE COSTS	Negligible	Less than USD5 per month	More than USD5 per months	More than USD100 per month	
TIME NEEDED TO CONSTRUCT	Insignificant	A few hours	A day	Several days to a week	Weeks
LEVEL OF EXPERTISE IN O&M	Unskilled	Local technician	Local government	External experts	
USER ACCEPTANCE	No activity	Limited extension	Considerable extension	Extensive campaign	

TR-08 Bioremediation

WATER SOURCE	Rainwater	Surface water	Brackish water	Groundwater	
MITIGATION	Arsenic	Salts			
LOCATION	Densely populated urban	Densely populated, low-income urban	Moderately populated urban	Peri-urban, rural	Rural, remote
ZONE IN BANGLADESH	Flood plain	Low water table area	Coastal zone	Low lying area / basin	Hilly region
SCALE OF IMPLEMENTATION	Household	Shared	Small community	School or institution	Large user group
PREFERRED LEVEL OF WATER DELIVERY	Household	Shared	Small community	School or institution	Large user group
PREFERRED MANAGEMENT LEVEL	Household	Shared	Small community	Municipal	
STATUS IN BANGLADESH	Widespread	Known	Little known	Unknown	
SYSTEM SOPHISTICATION	Labor-intensive	Intermediate	Technology-intensive		
GROUND FORMATION	Sand & gravel	Clay formations	Compacted formations	Soft weathered rock	Bedrock
WATER LIFTING	Not required	0-8 m	8-15 m	15-40 m	> 40 m
ENERGY AVAILABLE	None	Electricity grid	Fuel generated	Solar energy	Wind energy
FLOOD DANGER	Not affected	Only flooded in extreme weather	Annually affected by floods		
ACCESS TO SITE	On parcel	Outside of household area	Less than 10 minutes to access	Less than 30 minutes to access	More than 30 minutes to access
CONSTRUCTION COSTS	Negligible	Less than USD25	USD25-100	USD100-1,000	More than USD1,000
MAINTENANCE COSTS	Negligible	Less than USD5 per month	More than USD5 per months	More than USD100 per month	
TIME NEEDED TO CONSTRUCT	Insignificant	A few hours	A day	Several days to a week	Weeks
LEVEL OF EXPERTISE IN O&M	Unskilled	Local technician	Local government	External experts	
USER ACCEPTANCE	No activity	Limited extension	Considerable extension	Extensive campaign	

TR-09 Phytofiltration

WATER SOURCE	Rainwater	Surface water	Brackish water	Groundwater	
MITIGATION	Arsenic	Salts			
LOCATION	Densely populated urban	Densely populated, low-income urban	Moderately populated urban	Peri-urban, rural	Rural, remote
ZONE IN BANGLADESH	Flood plain	Low water table area	Coastal zone	Low lying area / basin	Hilly region
SCALE OF IMPLEMENTATION	Household	Shared	Small community	School or institution	Large user group
PREFERRED LEVEL OF WATER DELIVERY	Household	Shared	Small community	School or institution	Large user group
PREFERRED MANAGEMENT LEVEL	Household	Shared	Small community	Municipal	
STATUS IN BANGLADESH	Widespread	Known	Little known	Unknown	
SYSTEM SOPHISTICATION	Labor-intensive	Intermediate	Technology-intensive		
GROUND FORMATION	Sand & gravel	Clay formations	Compacted formations	Soft weathered rock	Bedrock
WATER LIFTING	Not required	0-8 m	8-15 m	15-40 m	> 40 m
ENERGY AVAILABLE	None	Electricity grid	Fuel generated	Solar energy	Wind energy
FLOOD DANGER	Not affected	Only flooded in extreme weather	Annually affected by floods		
ACCESS TO SITE	On parcel	Outside of household area	Less than 10 minutes to access	Less than 30 minutes to access	More than 30 minutes to access
CONSTRUCTION COSTS	Negligible	Less than USD25	USD25-100	USD100-1,000	More than USD1,000
MAINTENANCE COSTS	Negligible	Less than USD5 per month	More than USD5 per months	More than USD100 per month	
TIME NEEDED TO CONSTRUCT	Insignificant	A few hours	A day	Several days to a week	Weeks
LEVEL OF EXPERTISE IN O&M	Unskilled	Local technician	Local government	External experts	
USER ACCEPTANCE	No activity	Limited extension	Considerable extension	Extensive campaign	

TR-10 Permeable reactive barriers

WATER SOURCE	Rainwater	Surface water	Brackish water	Groundwater	
MITIGATION	Arsenic	Salts			
LOCATION	Densely populated urban	Densely populated, low-income urban	Moderately populated urban	Peri-urban, rural	Rural, remote
ZONE IN BANGLADESH	Flood plain	Low water table area	Coastal zone	Low lying area / basin	Hilly region
SCALE OF IMPLEMENTATION	Household	Shared	Small community	School or institution	Large user group
PREFERRED LEVEL OF WATER DELIVERY	Household	Shared	Small community	School or institution	Large user group
PREFERRED MANAGEMENT LEVEL	Household	Shared	Small community	Municipal	
STATUS IN BANGLADESH	Widespread	Known	Little known	Unknown	
SYSTEM SOPHISTICATION	Labor-intensive	Intermediate	Technology-intensive		
GROUND FORMATION	Sand & gravel	Clay formations	Compacted formations	Soft weathered rock	Bedrock
WATER LIFTING	Not required	0-8 m	8-15 m	15-40 m	> 40 m
ENERGY AVAILABLE	None	Electricity grid	Fuel generated	Solar energy	Wind energy
FLOOD DANGER	Not affected	Only flooded in extreme weather	Annually affected by floods		
ACCESS TO SITE	On parcel	Outside of household area	Less than 10 minutes to access	Less than 30 minutes to access	More than 30 minutes to access
CONSTRUCTION COSTS	Negligible	Less than USD25	USD25-100	USD100-1000	More than USD1,000
MAINTENANCE COSTS	Negligible	Less than USD5 per month	More than USD5 per months	More than USD100 per month	
TIME NEEDED TO CONSTRUCT	Insignificant	A few hours	A day	Several days to a week	Weeks
LEVEL OF EXPERTISE IN O&M	Unskilled	Local technician	Local government	External experts	
USER ACCEPTANCE	No activity	Limited extension	Considerable extension	Extensive campaign	

TR-11 Subsurface arsenic removal

WATER SOURCE	Rainwater	Surface water	Brackish water	Groundwater	
MITIGATION	Arsenic	Salts			
LOCATION	Densely populated urban	Densely populated, low-income urban	Moderately populated urban	Peri-urban, rural	Rural, remote
ZONE IN BANGLADESH	Flood plain	Low water table area	Coastal zone	Low lying area / basin	Hilly region
SCALE OF IMPLEMENTATION	Household	Shared	Small community	School or institution	Large user group
PREFERRED LEVEL OF WATER DELIVERY	Household	Shared	Small community	School or institution	Large user group
PREFERRED MANAGEMENT LEVEL	Household	Shared	Small community	Municipal	
STATUS IN BANGLADESH	Widespread	Known	Little known	Unknown	
SYSTEM SOPHISTICATION	Labor-intensive	Intermediate	Technology-intensive		
GROUND FORMATION	Sand & gravel	Clay formations	Compacted formations	Soft weathered rock	Bedrock
WATER LIFTING	Not required	0-8 m	8-15 m	15-40 m	> 40 m
ENERGY AVAILABLE	None	Electricity grid	Fuel generated	Solar energy	Wind energy
FLOOD DANGER	Not affected	Only flooded in extreme weather	Annually affected by floods		
ACCESS TO SITE	On parcel	Outside of household area	Less than 10 minutes to access	Less than 30 minutes to access	More than 30 minutes to access
CONSTRUCTION COSTS	Negligible	Less than USD25	USD25-100	USD100-1000	More than USD1,000
MAINTENANCE COSTS	Negligible	Less than USD5 per month	More than USD5 per months	More than USD100 per month	
TIME NEEDED TO CONSTRUCT	Insignificant	A few hours	A day	Several days to a week	Weeks
LEVEL OF EXPERTISE IN O&M	Unskilled	Local technician	Local government	External experts	
USER ACCEPTANCE	No activity	Limited extension	Considerable extension	Extensive campaign	

TR-12 Evaporation technologies

WATER SOURCE	Rainwater	Surface water	Brackish water	Groundwater	
MITIGATION	Arsenic	Salts			
LOCATION	Densely populated urban	Densely populated, low-income urban	Moderately populated urban	Peri-urban, rural	Rural, remote
ZONE IN BANGLADESH	Flood plain	Low water table area	Coastal zone	Low lying area / basin	Hilly region
SCALE OF IMPLEMENTATION	Household	Shared	Small community	School or institution	Large user group
PREFERRED LEVEL OF WATER DELIVERY	Household	Shared	Small community	School or institution	Large user group
PREFERRED MANAGEMENT LEVEL	Household	Shared	Small community	Municipal	
STATUS IN BANGLADESH	Widespread	Known	Little known	Unknown	
SYSTEM SOPHISTICATION	Labor-intensive	Intermediate	Technology-intensive		
GROUND FORMATION	Sand & gravel	Clay formations	Compacted formations	Soft weathered rock	Bedrock
WATER LIFTING	Not required	0-8 m	8-15 m	15-40 m	> 40 m
ENERGY AVAILABLE	None	Electricity grid	Fuel generated	Solar energy	Wind energy
FLOOD DANGER	Not affected	Only flooded in extreme weather	Annually affected by floods		
ACCESS TO SITE	On parcel	Outside of household area	Less than 10 minutes to access	Less than 30 minutes to access	More than 30 minutes to access
CONSTRUCTION COSTS	Negligible	Less than USD25	USD25-100	USD100-1,000	More than USD1,000
MAINTENANCE COSTS	Negligible	Less than USD5 per month	More than USD5 per months	More than USD100 per month	
TIME NEEDED TO CONSTRUCT	Insignificant	A few hours	A day	Several days to a week	Weeks
LEVEL OF EXPERTISE IN O&M	Unskilled	Local technician	Local government	External experts	
USER ACCEPTANCE	No activity	Limited extension	Considerable extension	Extensive campaign	

TR-13 Pond Sand Filter

WATER SOURCE	Rainwater	Surface water	Brackish water	Groundwater	
MITIGATION	Arsenic	Salts			
LOCATION	Densely populated urban	Densely populated, low-income urban	Moderately populated urban	Peri-urban, rural	Rural, remote
ZONE IN BANGLADESH	Flood plain	Low water table area	Coastal zone	Low lying area / basin	Hilly region
SCALE OF IMPLEMENTATION	Household	Shared	Small community	School or institution	Large user group
PREFERRED LEVEL OF WATER DELIVERY	Household	Shared	Small community	School or institution	Large user group
PREFERRED MANAGEMENT LEVEL	Household	Shared	Small community	Municipal	
STATUS IN BANGLADESH	Widespread	Known	Little known	Unknown	
SYSTEM SOPHISTICATION	Labor-intensive	Intermediate	Technology-intensive		
GROUND FORMATION	Sand & gravel	Clay formations	Compacted formations	Soft weathered rock	Bedrock
WATER LIFTING	Not required	0-8 m	8-15 m	15-40 m	> 40 m
ENERGY AVAILABLE	None	Electricity grid	Fuel generated	Solar energy	Wind energy
FLOOD DANGER	Not affected	Only flooded in extreme weather	Annually affected by floods		
ACCESS TO SITE	On parcel	Outside of household area	Less than 10 minutes to access	Less than 30 minutes to access	More than 30 minutes to access
CONSTRUCTION COSTS	Negligible	Less than USD25	USD25-100	USD100-1,000	More than USD1,000
MAINTENANCE COSTS	Negligible	Less than USD5 per month	More than USD5 per months	More than USD100 per month	
TIME NEEDED TO CONSTRUCT	Insignificant	A few hours	A day	Several days to a week	Weeks
LEVEL OF EXPERTISE IN O&M	Unskilled	Local technician	Local government	External experts	
USER ACCEPTANCE	No activity	Limited extension	Considerable extension	Extensive campaign	

TR-14 UV disinfection

WATER SOURCE	Rainwater	Surface water	Brackish water	Groundwater	
REMOVAL	Arsenic	Salts			
LOCATION	Densely populated urban	Densely populated, low-income urban	Moderately populated urban	Peri-urban, rural	Rural, remote
ZONE IN BANGLADESH	Flood plain	Low water table area	Coastal zone	Low lying area / basin	Hilly region
SCALE OF IMPLEMENTATION	Household8	Shared	Small community	School or institution	Large user group
PREFERRED LEVEL OF WATER DELIVERY	Household	Shared	Small community	School or institution	Large user group
PREFERRED MANAGEMENT LEVEL	Household	Shared	Small community	Municipal	
STATUS IN BANGLADESH	Widespread	Known	Little known	Unknown	
SYSTEM SOPHISTICATION	Labor-intensive	Intermediate	Technology-intensive		
GROUND FORMATION	Sand & gravel	Clay formations	Compacted formations	Soft weathered rock	Bedrock
WATER LIFTING	Not required	0-8 m	8-15 m	15-40 m	> 40 m
ENERGY AVAILABLE	None	Electricity grid	Fuel generated	Solar energy	Wind energy
FLOOD DANGER	Not affected	Only flooded in extreme weather	Annually affected by floods		
ACCESS TO SITE	On parcel	Outside of household area	Less than 10 minutes to access	Less than 30 minutes to access	More than 30 minutes to access
CONSTRUCTION COSTS	Negligible	Less than USD25	USD25-100	USD100-1000	More than USD1,000
MAINTENANCE COSTS	Negligible	Less than USD5 per month	More than USD5 per months	More than USD100 per month	
TIME NEEDED TO CONSTRUCT	Insignificant	A few hours	A day	Several days to a week	Weeks
LEVEL OF EXPERTISE IN O&M	Unskilled	Local technician	Local government	External experts	
USER ACCEPTANCE	No activity	Limited extension	Considerable extension	Extensive campaign	

TR-15 Chlorination

WATER SOURCE	Rainwater	Surface water	Brackish water	Groundwater	
MITIGATION	Arsenic	Salts			
LOCATION	Densely populated urban	Densely populated, low-income urban	Moderately populated urban	Peri-urban, rural	Rural, remote
ZONE IN BANGLADESH	Flood plain	Low water table area	Coastal zone	Low lying area / basin	Hilly region
SCALE OF IMPLEMENTATION	Household	Shared	Small community	School or institution	Large user group
PREFERRED LEVEL OF WATER DELIVERY	Household	Shared	Small community	School or institution	Large user group
PREFERRED MANAGEMENT LEVEL	Household	Shared	Small community	Municipal	
STATUS IN BANGLADESH	Widespread	Known	Little known	Unknown	
SYSTEM SOPHISTICATION	Labor-intensive	Intermediate	Technology-intensive		
GROUND FORMATION	Sand & gravel	Clay formations	Compacted formations	Soft weathered rock	Bedrock
WATER LIFTING	Not required	0-8 m	8-15 m	15-40 m	> 40 m
ENERGY AVAILABLE	None	Electricity grid	Fuel generated	Solar energy	Wind energy
FLOOD DANGER	Not affected	Only flooded in extreme weather	Annually affected by floods		
ACCESS TO SITE	On parcel	Outside of household area	Less than 10 minutes to access	Less than 30 minutes to access	More than 30 minutes to access
CONSTRUCTION COSTS	Negligible	Less than USD25	USD25-100	USD100-1,000	More than USD1,000
MAINTENANCE COSTS	Negligible	Less than USD5 per month	More than USD5 per months	More than USD100 per month	
TIME NEEDED TO CONSTRUCT	Insignificant	A few hours	A day	Several days to a week	Weeks
LEVEL OF EXPERTISE IN O&M	Unskilled	Local technician	Local government	External experts	
USER ACCEPTANCE	No activity	Limited extension	Considerable extension	Extensive campaign	

TR-16 Boiling

WATER SOURCE	Rainwater	Surface water	Brackish water	Groundwater	
REMOVAL	Arsenic	Salts			
LOCATION	Densely populated urban	Densely populated, low-income urban	Moderately populated urban	Peri-urban, rural	Rural, remote
ZONE IN BANGLADESH	Flood plain	Low water table area	Coastal zone	Low lying area / basin	Hilly region
SCALE OF IMPLEMENTATION	Household	Shared	Small community	School or institution	Large user group
PREFERRED LEVEL OF WATER DELIVERY	Household	Shared	Small community	School or institution	Large user group
PREFERRED MANAGEMENT LEVEL	Household	Shared	Small community	Municipal	
STATUS IN BANGLADESH	Widespread	Known	Little known	Unknown	
SYSTEM SOPHISTICATION	Labor-intensive	Intermediate	Technology-intensive		
GROUND FORMATION	Sand & gravel	Clay formations	Compacted formations	Soft weathered rock	Bedrock
WATER LIFTING	Not required	0-8 m	8-15 m	15-40 m	> 40 m
ANNUAL PRECIPITATION	< 200 mm	> 200 mm; seasonal	> 200 mm; year-round		
ENERGY AVAILABLE	None	Electricity grid	Fuel generated	Solar energy	Wind energy
FLOOD DANGER	Not affected	Only flooded in extreme weather	Annually affected by floods		
ACCESS TO SITE	On parcel	Outside of household area	Less than 10 minutes to access	Less than 30 minutes to access	More than 30 minutes to access
CONSTRUCTION COSTS	Negligible	Less than USD25	USD25-100	USD100-1,000	More than USD1,000
MAINTENANCE COSTS	Negligible	Less than USD5 per month	More than USD5 per months	More than USD100 per month	
TIME NEEDED TO CONSTRUCT	Insignificant	A few hours	A day	Several days to a week	Weeks
LEVEL OF EXPERTISE IN O&M	Unskilled	Local technician	Local government	External experts	
USER ACCEPTANCE	No activity	Limited extension	Considerable extension	Extensive campaign	

TR-17 Ceramic pot filter

WATER SOURCE	Rainwater	Surface water	Brackish water	Groundwater	
REMOVAL	Arsenic	Salts			
LOCATION	Densely populated urban	Densely populated, low-income urban	Moderately populated urban	Peri-urban, rural	Rural, remote
ZONE IN BANGLADESH	Flood plain	Low water table area	Coastal zone	Low lying area / basin	Hilly region
SCALE OF IMPLEMENTATION	Household	Shared	Small community	School or institution	Large user group
PREFERRED LEVEL OF WATER DELIVERY	Household	Shared	Small community	School or institution	Large user group
PREFERRED MANAGEMENT LEVEL	Household	Shared	Small community	Municipal	
STATUS IN BANGLADESH	Widespread	Known	Little known	Unknown	
SYSTEM SOPHISTICATION	Labor-intensive	Intermediate	Technology-intensive		
GROUND FORMATION	Sand & gravel	Clay formations	Compacted formations	Soft weathered rock	Bedrock
WATER LIFTING	Not required	0-8 m	8-15 m	15-40 m	> 40 m
ENERGY AVAILABLE	None	Electricity grid	Fuel generated	Solar energy	Wind energy
FLOOD DANGER	Not affected	Only flooded in extreme weather	Annually affected by floods		
ACCESS TO SITE	On parcel	Outside of household area	Less than 10 minutes to access	Less than 30 minutes to access	More than 30 minutes to access
CONSTRUCTION COSTS	Negligible	Less than USD25	USD25-100	USD100-1,000	More than USD1,000
MAINTENANCE COSTS	Negligible	Less than USD5 per month	More than USD5 per months	More than USD100 per month	
TIME NEEDED TO CONSTRUCT	Insignificant	A few hours	A day	Several days to a week	Weeks
LEVEL OF EXPERTISE IN O&M	Unskilled	Local technician	Local government	External experts	
USER ACCEPTANCE	No activity	Limited extension	Considerable extension	Extensive campaign	

TR-18 Infiltration galleries

WATER SOURCE	Rainwater	Surface water	Brackish water	Groundwater	
REMOVAL	Arsenic	Salts			
LOCATION	Densely populated urban	Densely populated, low-income urban	Moderately populated urban	Peri-urban, rural	Rural, remote
ZONE IN BANGLADESH	Flood plain	Low water table area	Coastal zone	Low lying area / basin	Hilly region
SCALE OF IMPLEMENTATION	Household	Shared	Small community	School or institution	Large user group
PREFERRED LEVEL OF WATER DELIVERY	Household	Shared	Small community	School or institution	Large user group
PREFERRED MANAGEMENT LEVEL	Household	Shared	Small community	Municipal	
STATUS IN BANGLADESH	Widespread	Known	Little known	Unknown	
SYSTEM SOPHISTICATION	Labor-intensive	Intermediate	Technology-intensive		
GROUND FORMATION	Sand & gravel	Clay formations	Compacted formations	Soft weathered rock	Bedrock
WATER LIFTING	Not required	0-8 m	8-15 m	15-40 m	> 40 m
ANNUAL PRECIPITATION	< 200 mm	> 200 mm; seasonal	> 200 mm; year-round		
ENERGY AVAILABLE	None	Electricity grid	Fuel generated	Solar energy	Wind energy
FLOOD DANGER	Not affected	Only flooded in extreme weather	Annually affected by floods		
ACCESS TO SITE	On parcel	Outside of household area	Less than 10 minutes to access	Less than 30 minutes to access	More than 30 minutes to access
CONSTRUCTION COSTS	Negligible	Less than USD25	USD25-100	USD100-1,000	More than USD1,000
MAINTENANCE COSTS	Negligible	Less than USD5 per month	More than USD5 per months	More than USD100 per month	
TIME NEEDED TO CONSTRUCT	Insignificant	A few hours	A day	Several days to a week	Weeks
LEVEL OF EXPERTISE IN O&M	Unskilled	Local technician	Local government	External experts	
USER ACCEPTANCE	No activity	Limited extension	Considerable extension	Extensive campaign	

TR-19 Riverbank filtration

WATER SOURCE	Rainwater	Surface water	Brackish water	Groundwater	
REMOVAL	Arsenic	Salts			
LOCATION	Densely populated urban	Densely populated, low-income urban	Moderately populated urban	Peri-urban, rural	Rural, remote
ZONE IN BANGLADESH	Flood plain	Low water table area	Coastal zone	Low lying area / basin	Hilly region
SCALE OF IMPLEMENTATION	Household	Shared	Small community	School or institution	Large user group
PREFERRED LEVEL OF WATER DELIVERY	Household	Shared	Small community	School or institution	Large user group
PREFERRED MANAGEMENT LEVEL	Household	Shared	Small community	Municipal	
STATUS IN BANGLADESH	Widespread	Known	Little known	Unknown	
SYSTEM SOPHISTICATION	Labor-intensive	Intermediate	Technology-intensive		
GROUND FORMATION	Sand & gravel	Clay formations	Compacted formations	Soft weathered rock	Bedrock
ANNUAL PRECIPITATION	< 200 mm	> 200 mm; seasonal	> 200 mm; year-round		
ENERGY AVAILABLE	None	Electricity grid	Fuel generated	Solar energy	Wind energy
FLOOD DANGER	Not affected	Only flooded in extreme weather	Annually affected by floods		
ACCESS TO SITE	On parcel	Outside of household area	Less than 10 minutes to access	Less than 30 minutes to access	More than 30 minutes to access
CONSTRUCTION COSTS	Negligible	Less than USD25	USD25-100	USD100-1,000	More than USD1,000
MAINTENANCE COSTS	Negligible	Less than USD5 per month	More than USD5 per months	More than USD100 per month	
TIME NEEDED TO CONSTRUCT	Insignificant	A few hours	A day	Several days to a week	Weeks
LEVEL OF EXPERTISE IN O&M	Unskilled	Local technician	Local government	External experts	
USER ACCEPTANCE	No activity	Limited extension	Considerable extension	Extensive campaign	

Annex 2 Inventory of the interviewed organizations and their profiles

Because of the large diversity in expertise, activity and scale of organization, open ended interviews were executed with water experts. These were in almost all cases coupled to the filling in of a questionnaire by the interviewed expert. The questionnaire had the same structuring as the technology information sheets. (The raised questions are described in section 6.) Analysis of the responses was structured and cross-checked with information from other experts both in the technology information sheets as in the eligibility matrices.

The interview questions followed the following structuring:

i. which arsenic- or salt-mitigation projects the interviewee participated in, what was the volume and impact of the project and what was their own role in the project;
ii. what was the long-term impact of the project (with regard to success rate and longevity of sustainably managed deliverables, sub-project units, installations and/or services;
iii. what were the key aspects that contributed to the failure of the project
    1. with regard to user acceptance
    2. financial strategy (both implementation and pricing of service)
    3. management/institutional affairs,
    4. technological selection,
    5. what would be their preferred approach or solution in avoiding such failures in the future.
iv. what were the key aspects that contributed to the (partial or complete) success of the project
    1. with regard to user acceptance,
    2. financial strategy (both implementation and pricing of service),
    3. management/institutional affairs,
    4. technological choice,
    5. why are these aspects so crucial for resilient operation.
v. What formal publications are available that detail and analyze the described project(s)

CONTRIBUTING INTERNATIONAL DEVELOPMENT ORGANIZATIONS OR THEIR LOCAL (BANGLADESHI) COUNTERPARTS

Organization	Main activities	Contact information	Expert interviewed
Acacia Water	Research in collaboration with Dhaka University and DPHE on infiltration of rainwater into shallow (brackish) aquifers; securing drinking water supply during dry season	www.acaciawater.com +31(0) 182686424	Albert Tuinhof
DANIDA	Support to policy and strategy work in Local Government Division and provision of hygiene promotion, sanitation and water supply services through Union Parishads	bangladesh.um.dk/en/danida-en	ETBI*
EAWAG	Improved technologies for arsenic mitigation; analysis of socio-economic and institutional conditions, enabling implementation and maintenance of risk mitigation measures; analysis of social acceptance and use of arsenic mitigation options and evaluation of promotion strategies	www.eawag.ch +41 (0)58 765 55 11	Dr. Hansi Mosler Dr. Stephan Hug
GIZ	Solar powered pumps to supply drinking water in areas prone to arsenic contamination and salinity	www.giz.de/en/worldwide/351.html giz-bangladesh@giz.de	Mohammed Khalequzzaman
ICCO	Diverse WASH activities, primary involvement in technical As-mitigation include support in implementation of tube well, pond sand filter and rainwater harvesting methods	www.icco-international.com + 31(0)30 - 692 78 11	Leonard Zijlstra
IRC International Water and Sanitation Center	Supports the BRAC WASH program	www.ircwash.org +31 70 304 4000	Ingeborg Krukkert, Jan Willem Dogger
Japan International Cooperation Agency (JICA)	Urban water supply projects	www.jica.go.jp/bangladesh/english	STS; Mr. Md. Anisuzzaman
Joint Monitoring Program (JMP)	WHO-UNICEF Joint Monitoring Programme (JMP)	www.wssinfo.org	Dr. Rick Johnston

	for Water Supply and Sanitation		
Max Foundation	Deep tube wells (e.g. 2012: 398 wells)	www.maxfoundation.org +31-20 611 76 74	Joke le Poole
OXFAM	Deep tube wells, Kolshi filter, Chuili Filter, Rain water harvesting, Pond sand filter	www.oxfam.org/en/bangladesh	ETBI
UNICEF	Very broad range of methods implemented and disseminated in Bangladesh. Most noteworthy recent activities: SHEWA-B, MAR pilots, small piped networks and As-safe model villages	www.unicef.org/bangladesh 880 2 885 2266	Nargis Akter
WaterAid	Help poor communities living in slums of major cities to gain access to communal water points and sanitation blocks. In areas of Chittagong Hill Tracts, helped villagers to construct gravity flow water schemes. In low-lying areas prone to monsoon flooding, helping communities to construct water and sanitation facilities that are more resilient to disasters and impacts of climate change	www.wateraid.org/bangladesh 880 28815757	STS; Mr. Hasin Jahan
WSP - World Bank	Advocating policy reform, improved regulatory frame work and promoting scaling up, replication of good practices; capacity building of local and central government institutions; community participation and partnerships among local stakeholders in WATSAN service delivery models; empowerment of poor, extreme poor and women	www.worldbank.org/bangladesh (880-2) 8159001	STS; Mr.A. K. M. Waliul

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CONTRIBUTING BANGLADESHI ORGANIZATIONS (COMPLETED AFTER WORKSHOP)

Organization	Main activities	Contact information	Expert interviewed
Ashroy Foundation	Deep tube wells, AIRP, Rain Water Harvesting Plant, Pond Sand Filter, Pond Re-excavation	www.ashroyfoundation.org +88-01711004579	Momotaz Khatun
Bangladesh Agricultural Development Corporation (BADC)	Provision of surface and groundwater-based irrigation facilities to farmers	www.badc.gov.bd +880 2-9564357	ETBI*
Bangladesh Association for Social Advancement (BASA)	Arsenic Iron Removal Plant (AIRP) - HH Based, Rain water harvesting and recharge	www.basango.org +8801711-528281	A. K. M. Shirajul Islam
Bangladesh University of Engineering and Technology (BUET)	Activated alumina and other thematic activities, e.g. around social acceptance.	www.buet.ac.bd +880 2-9665650	Prof. Borhan Badruzzaman
Bangladesh Water Development Board (BWDB)	Principal agency of the government for managing water resources of the country.	www.bwdb.gov.bd	ETBI
BRAC	Provides sustainable and integrated WASH services primarily in rural and isolated areas. National lead agency for provision of drinking water supply and waste management primarily in rural and isolated areas in Bangladesh	www.brac.net + 880-2-9881265, 8824180-7	Dr. Mofazzal Hoque
Dalit	Deep tube wells, Intermediate tube wells/Shallow Tube well, Arsenic removal from groundwater, Rain water harvesting and recharge, Pond sand filter	www.dalitbd.org +88- 01913287437	Mr. Gorachand Biswas
Department of Public Health Engineering (DPHE)	Deep tube wells, Shallow Tube Well, Shallow Shrouded Tube Well, Ring Well, Rain water harvesting and recharge, Infiltration Gallery	www.dphe.gov.bd + 88-02-9343358	Mr. Md. Nuruzzaman Mr. Saifur Rahman (R&D Division)
Development Organisation for the	Deep tube wells	www.dorpbd.org	Mr. Didar Uddin

Organization	Main activities	Contact information	Expert interviewed
Rural Poor (DORP)		88-02-8034785-6	
DSK	Tube wells	www.dskbangladesh.org +8801711-308978	Mr. Abdul Hakim
Eco-Social Development Organization	Tube wells, Rain Water Harvesting System	www.esdo-bangladesh.org +88-01713149202	Atal Kumar Mazumder
EPRC	Creating Arsenic Safe villages with user women led sustainable improvement of water; Demonstrating the Value of Greater Women Involvement in Implementing Arsenic Mitigation Water Supply in Bangladesh; Sustainable Involvement of Empowered Women in the Arsenic Porn Southwest Area Integrated Water Resources Planning and Management Project; Women-led Improved Access to Safe Drinking Water and Environmental Health in Water Stressed Climate Vulnerable areas of Bangladesh	www.eprcbd.org 880-2- 8822772	Prof. Bilqis Hoque
Friendship	Community-based Water Treatment Plants	www.friendship-bd.org +8801713-083433	STS; Mr. Hasibul Mannan
Gana Unnayan Kendra (GUK)	Deep tube wells, Shallow Tube wells, Arsenic Iron Removal Plant (AIRP)	www.guk.com +88-01713484612	Mr. Tushar
Gano Milan Foundation (GMF)	Deep tube wells, Rain water harvesting and recharge (both community and household based), Managed aquifer recharge	rsr.akvo.org/organisation/1022 +88- 01711814196	Mr. Ranjit Kumar Biswas
Gram Unnayon Sangathon (GRAUS)	Water and sanitation facilities	www.graus-cht.org 880-361-62104	ETBI

Organization	Main activities	Contact information	Expert interviewed
Hope for the Poorest (HP)	Deep tube wells, Arsenic Iron Removal Plants (AIRP)	www.hp-bd.org +88-01722873550	Mrs. Fauzia Alam (Chadni)
Jagrata Juba Sangha (JJS)	Deep tube wells, Rain Water Harvesting Plant, Pond Sand Filter, MAR	www.jjsbangladesh.org +88-01712862115	Md. Nazmul Huda
Mukti Foundation (MF)	Deep tube wells, Arsenic Iron Removal Plants (AIRP), Rain water harvesting and recharge (both community and household based), Pond sand filter, Managed aquifer recharge	www.washbd.org/?page_id=149 +88-01716840797	Mr. Gobinda Ghosh
NGO Forum	Rain-water Harvesting System, Pond Sand Filter (PSF)/Lake Sand Filter (LSF)/River Sand Filter (RFS), Ring-well/ Dug-well, Shallow Tubewell, Deep Tubewell/ Deep-set Pump.	www.ngof.org +880-2-8154273-4, 8128258-9	STS; S. M. A. Rashid
Practical Action Bangladesh	Rain water harvesting systems (both household and community based), Arsenic and Iron removal plants, bio-sand filter in arsenic and iron prone areas	www.practicalaction.org/Bangladesh +880 (0) 2-8650439, 9675236, 9675243	Mr. Dipok Chandra Roy
Shushilan	Innovative Approaches to Restore the Productivity of Natural Resources that are Resilient to Climate Change and Increasing Salinity	www.shushilan.org +8801713-423237	STS; Mr. Md. Rafiqul Haque
Society for People's Action in Change and Equity (SPACE)	Deep Tube Well, Shallow Tube Well, Infiltration Gallery, Arsenic Iron Removal Plant, Kolshi filter, Rain water harvesting and recharge (HH based)	www.spacebangladesh.org +88-01716-209334	Mr. Salah Uddin Titol
Unnayan Shahojogy Team (UST)	Deep tube wells, Hand tube wells, Arsenic Iron Removal Plant, F-CUBED Water Purification Plant, Small piped networks, Sono Filter, Rain Water Harvesting System, Pond Sand Filter	www.ustbd.org +88-01718000277	Mr. A. K. M. Rafiqul Islam

Organization	Main activities	Contact information	Expert interviewed
University of Dhaka	Several research projects on arsenic and salt mitigation	www.du.ac.bd (880)-2-8614150	Prof. Kazi Matin Ahmed
Uttaran	Deep tube wells, Intermediate tube wells, Rain water harvesting and recharge (both community based and household based), Pond sand filter	www.uttaran.net +88-02-9122302	Mr. Pijush Barai
Uttara University	See EPRC	www.uttarauniversity.edu.bd 8919794, 8919116, 8912280	Prof. Bilqis Hoque
Village Education Resource Center (VERC)	Deep tube wells, Household based Sono Filter, Small piped networks, Rain Water Harvesting Plant (Household Based and Community Based)	www.verc.org +88-01713017064	Mr. Md. Masud Hassan

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