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Decision-support for arsenic- and salt-mitigation in Bangladesh: the ASTRA approach

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REFEREED PAPER

Bangladesh faces a growing water crisis. Limitations to safe water access arise from the widespread pathogenic contamination of its waters, the severe arsenic contamination of its aquifers and the growing salinity in the country's coastal regions. Although appropriate methods are identified for some of these contexts, it is particularly complex to determine resilient water supply solutions for the low-income, rural areas of Bangladesh. The ASTRA tool is developed to support the identification of potentially appropriate drinking water methods in this context. It can be seen as the combination of a multidisciplinary sourcebook and a decision-support instrument. This paper outlines the three main mitigation routes involved as the (i) targeting of contamination-free groundwater, (ii) treatment of arsenic- and salt-contaminated aquifers and (iii) utilization of non-groundwater sources. The paper also describes the included water supply methods and related context factors that were used to determine the functional ranges of each method included.

A growing water crisis in Bangladesh

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. 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). In the recent past, the increasing population pressure and the related environmental load resulted in a growing pathogenic contamination of surface water streams. The continued use of these water sources led to frequent epidemics that shifted focus to the use of ground- and rainwater sources (Field *et al.*, 2011). At present, still about 79 % of all drinking water is estimated to be withdrawn from diverse groundwater sources (FAO-AQUASTAT, 2013).

In 1993, the naturally occurring arsenic was discovered in the groundwater (Kinniburgh and Smedley, 2001). 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). Saline intrusion – as a result of climate change – 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, its effect goes beyond the water sector and affects the country's food sovereignty as well.

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. 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 constrain 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 decision-support tool (ASTRA) that focuses on the identification of potentially appropriate, arsenic- and salt-mitigating water methods for diverse Bangladeshi implementation contexts.

Decision-support approaches for increased sustainability

The implementation and use of appropriate methods is a key prerequisite in achieving an improved water sector. The selection of appropriate technological methods 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.

Such an infrastructural grid is limited in most developing countries. Even where standardized water supply methods are widespread (e.g. a central water treatment and supply chain), these are 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. In their place, decentralized, often on-site methods are the dominant choices for water access. The diversity of decentralized methods implies that their efficient use depends largely on the context where they are applied in. this notion raises the importance of having reliable information at hand that helps determining whether a specific decentralized method is the proper choice in any given project context. To tackle this problem, several knowledge bases (compendia) were developed in the recent past. While some of these compendia are developed to ensure (multidisciplinary) knowledge dissemination regarding the contained technologies (e.g. the SSWM (2012) or Akvopedia (2011) portals), others include both dissemination and decision-support functions. Decision-support tools can be defined as instruments that offer information to aids the determination of method applicability in predefined contexts. Examples to such tools include the EAWAG compendium (Tilley *et al.*, 2008) or the online WaterCompass (PRACTICA *et al.*, 2013).

Methodology

The research for the development of the ASTRA decision-support tool focused on the acquisition, analysis and synthesis of information regarding water methods applied in arsenic- and salt-mitigation in and outside of 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 the practical functioning of existing methods, so the approached experts were interviewed in open ended discussions to offer their view (ASTRA, *in preparation*). The scope of analyzed methods contains

- best practice technologies involved in arsenic- and salt-mitigation in Bangladesh,
- sustainable technologies for arsenic- and salt-removal in an international, development-context,
- high-tech technologies potentially relevant for Bangladeshi arsenic- and salt-mitigation, and
- promising arsenic- and salt-removal methods still in development.

The selected and methods were subject to analysis according to a number of context factors and their options. 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.

The ASTRA tool

Description of tool structure

The ASTRA arsenic- and salt-mitigation 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 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, a total of 21 factors were identified (Table 1). These factors were classified in three groups. These groups are meant to define the natural, human and technical context in which the water method will need to function. Natural context factors are included as they determine the (largely) unalterable traits of the given situation.

Human factors may be alterable (e.g. with behavior change campaigns), but any change is likely to require considerable efforts and time. In general, technical factors 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. 25 source development, conveyance and treatment methods were grouped according to three mitigation approaches Table 2). These three method groups include

1. Arsenic- and salinity-free groundwater abstraction;
2. Treatment of arsenic- or salt-containing groundwater; and
3. Appropriate, non-groundwater solutions including surface and rainwater options.

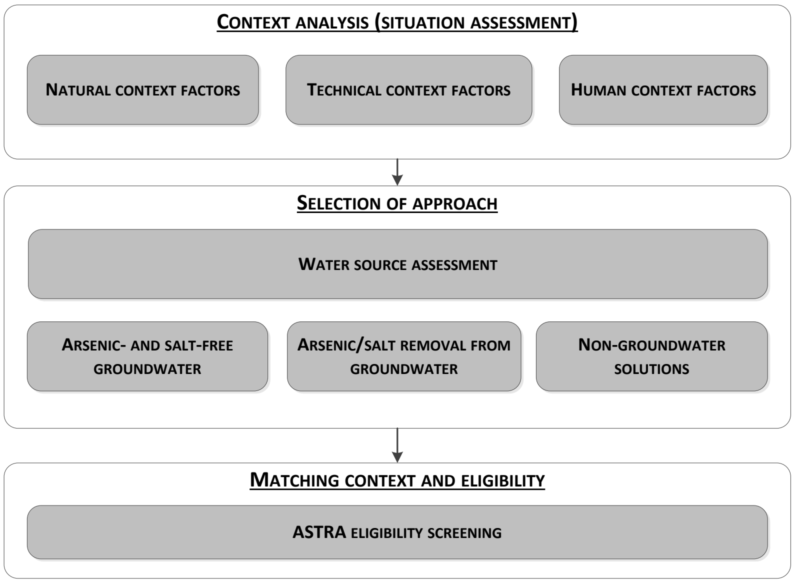

Figure 1. Schematic structure of the ASTRA decision-support tool

The third stage of the tool considers the matching of the initially defined context factor options and the functionality of the included methods. This occurs with the support of the functionality matrices that are predefined for each method and contain the level of applicability of the method for each of the context options of the tool.

The context analysis

Analysis of an affected area or 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 the analysis factors to elements with 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 from an implemented solution. However, such information is most often not available or hard to define properly without executing extensive survey and research. 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. Only those factors are included in the ASTRA tool that can support a meaningful classification.

Table 1. Context criteria and their respective options

	Criterion	Included options	Featured aspect
Natural context factors	**Water source**	Surface, brackish, rain- and groundwater	Locality of water body
	Removal	Arsenic, salt	Arsenic or salt
	Ground formation	Sand & 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
Human context factors	**Location**	Densely populated urban; densely pop., low-income urban; moderately pop. urban, peri-urban, rural and rural-remote	Settlement type and population density
	Site selection	Settlement, agricultural and coastal	Type of location
	Implementation scale	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, <10 minutes to access, <30 minutes and >30 minutes	Means of accessibility to water point
Technical context factors	**Status in Bangladesh**	Widespread, known, little known, unknown	Level of embeddedness
	System sophistication	Labor-intensive, intermediate and technology-intensive	Labor-using or automated process
	Water transport	Manual, animal and motorized	Water transport options
	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	None, a day, less than a week and weeks	Typical construction time
	Level of expertise-O&M	Household, local technician, local government and external experts	Required level of skills in O&M
	User acceptance	No activity, limited extension, considerable extension and extensive campaign	Level of requirement to inform user about use

Compendium of potential mitigation methods

Figure 2 contains the method inventory of the ASTRA tool. In the tool, each of the 25 methods is complete with a multidisciplinary description and a functionality matrix. In the matrix each of the context factors are included and each of their options is evaluated according to the actual functioning of the relevant water method. In the ASTRA tool, functioning is classified into four distinctive categories:

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

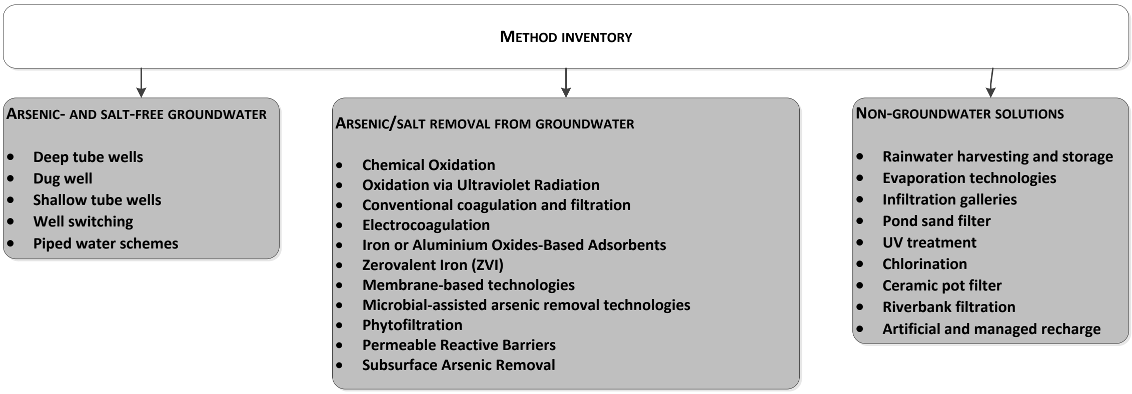

Figure 2. Methods and classification of the ASTRA tool

Matching of context and eligibility

The eligibility screening is in essence a multicriteria analysis[1] that offers an aggregated, multidisciplinary output on method eligibility. This eligibility output is kept very simple in order to ensure that tool users can always understand which aspect(s) of a method are fully or only partially eligible. The tool use implies that the tool user compares his or her context scenario to the functionality matrices in the tool.

In an optimal situation, a method may score appropriate for each factor, making it fully appropriate for the intended project context. More often, some of the viewed factors are likely to be only partially 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 the intended project context. A viewing of the method description then offers a basic advice on the reason of limitation or ineligibility.

Strengths and weaknesses of the ASTRA tool

The screening process is simple as it operates with a one-step multicriteria analysis. This simplicity offers a transparency that improves the understanding of method appropriateness. In this context, it implies that anyone using the tool can easily 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 ASTRA tool is not meant to replace water experts but to aid them in identifying the potentially most optimal 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 emphasizes that in reality no strategy can account for every local alteration in the functionality of a method. As the tool only offers an appropriateness screening, its output (the pool of potentially applicable methods) still needs to be assessed. This should optimally occur in a multistakeholder setting, where the participants can view and evaluate the selected methods. For this task, several instruments are available (e.g. the WASHTech project tools (Olchewski *et al.*, 2012)).

The simplified screening process implies that the tool quality is primarily based on the quality of its content. 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. Some of the contained information is liable to changes over time. This necessitates regular reviewing of the reliability of the tool, but it also implies that future methods can be included as well. As the tool offers a standardized description format, the new methods can be easily compared to the already included methods.

Final remarks

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

- decision-support instead of –making
- an extensive, peer reviewed 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.

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Note

[1] www.astradst.info

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